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LIGHT, VISION AND SEEING

A Simplified Presentation of Their Relationships
and
Their Importance in Human Efficiency and Welfare

BY

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Foreword

Food, air and living are simple common words, but their commonplaceness does not conceal their fundamental importance to human beings. The need for food is demonstrated daily and the need for air is quickly obvious. Their relationship to living is equally emphatic; and living is always in bold relief against the inevitability of death.

Light, vision and seeing are also simple common words, but their commonplaceness seems to obscure their overwhelming importance in human activities. Seeing is a great part of the utility and pleasure of living. Total blindness is relatively rare and only the blind, after having seen, can fully appraise the value of vision and its essential partner, light. Commonplace inadequacies in light and in seeing conditions are not generally obvious. Eyes are more patient and less complaining than lungs or stomach.

In an age which has witnessed great strides in making life better and work easier, the burdens upon eyes and the responsibilities of seeing have greatly increased. In this same period, progress in the production and control of artificial light has been truly enormous. Since Gutenberg laid the foundation for printing, the efficiency of light-production has increased a hundredfold and more. However, knowledge of the relationships of light and vision, and of these to the countless tasks of seeing, did not keep pace with the increase in the demands upon eyesight and upon seeing.

Depending upon the use of light, considered in terms of brightness and fitted to the task and to the limitations and abilities of the visual sense, seeing may be adequate or inadequate, certain or uncertain, easy or difficult. For any individual the ability of his visual sense is fixed for any given set of conditions;

but it may be greatly extended by external controllable factors such as light, brightness, lighting and brightness-contrast. Such factors determine the visibility of visual tasks and whether seeing conditions are good or bad. All the controllable external factors determine whether or not the eyes are to be unnecessarily overburdened while performing prolonged tasks of seeing for hours daily throughout lifetimes. And the effects of seeing go beyond the eyes and draw upon the resources of the entire human being. These, and other resources, may be wasted or conserved. Overwhelmingly throughout civilized activities, the efficiency, safety and welfare of human beings depend upon quick, certain, safe and easy seeing.

Owing to the omnipotence of seeing in civilized activities, it is not surprising that various professions, organizations and industries, as well as many individuals, are in a position to make seeing easier and thereby decrease the penalties and economic wastes due to generally poor seeing conditions. Naturally each of these can play only a part, but all combined can do much toward conserving vision and other resources. Although the effects of seeing extend far beyond the eyes into the physiological realm of the human being, eventually affecting his behavior and finally his efficiency and welfare, it is sufficient for the purpose of this foreword to emphasize eyesight and the conservation of vision and other resources.

First, one must recognize the enormous change which civilization has brought about in the use of our eyes. From this viewpoint our artificial world is largely within arm's reach. Civilized human beings and their eyes are chained like galley slaves to tasks of near-vision for long periods daily. This continues from the time that children enter school, throughout their lives. That this slavery to near-vision is unnatural is axiomatic. What the ultimate consequences are no one knows with certainty, but it is obvious that these burdens can be lessened by every means which makes seeing easier.

We are confronted with certain facts of statistics which should arouse us. Viewed collectively, eyesight deteriorates from the time that children enter school, and this continues throughout life. The prevalence of eye-defectiveness and of eyestrain disorders varies markedly with occupation. These two facts should arouse widespread interest and suspicion. However, they are viewed with apparent complacency by many individuals and some organizations which should not be complacent. Worse still, there is much evidence that eye-defects, particularly of the refractive type, are in effect accepted as inevitable. But is it not just as necessary to prove that these are inevitable as it is to prove that the percentage and degree of eye-defectiveness can be decreased by making seeing easier?

Such indictments are mitigated, to some extent at least, when we take into account that only in the last decade or two has an appropriate interest been directed toward seeing as distinguished from vision. Seeing is a complex human activity performed with the two essential tools, light and vision. The science of seeing until relatively recently was given little or no attention as such. In fact, the term has been in use less than a score of years. As a science it is far from complete, but at least it is now a concept of appropriate magnitude which includes the science of vision and much more. But as yet there are no full-fledged seeing specialists serving our artificial world of civilization which has been built largely by and for seeing.

Eyesight specialists care for eyes in their offices and surgeries. Few of them follow eyes into the world of use and abuse. They know much about vision but, for obvious reasons, their techniques and their knowledge do not deal primarily with the activity of seeing and with the countless tasks of seeing in our modern world of seeing. Many eyesight specialists are sincerely interested in making seeing better and easier, but the very nature of their practice gives them little opportunity to serve directly. They provide eyeglasses which are invaluable to the large and increasing percentage of persons who wear them. These are excellent crutches. They ease some of the burden of modern seeing but they do not reach beyond to other factors upon which seeing and seeing conditions depend. Eyeglasses do not deal with the possible causes of some percentage and degree of eye-defects.

Some welfare organizations have done well in conserving vision, particularly at birth, and some have done much toward the prevention of accidents to eyes. They can do much more as they accept and follow the dictates of the increasing knowledge of seeing. Medical practice, and all other practices, are continually accepting new dictates from the sciences upon which they are built. It is reasonably certain that the percentage of eye-defectiveness and particularly the degree of eye-defectiveness can be reduced by a better understanding and use of various factors which increase the visibility of prolonged visual tasks and make seeing easier.

No profession, organization, or industry has a monopoly on either the responsibility or opportunity for easing the burdens upon human eyes and upon human seeing-machines. There is adequate need for the effort and interest of every group and individual that can help. Civilization as a whole is the trustee of eyesight and of other natural endowments, and of the resources that play a part in seeing or are affected by it. Civilization is the trustee of these, for this and for future generations. Eventually it will hold all responsible for whatever neglect of opportunity they have been guilty of.

This book was written in response to many requests from individuals of a variety of interests, for a simplified presentation of the relationships of light, brightness, vision, lighting and seeing. These are extensive complex subjects and, therefore, their relationships are even more complex. Simplification can be carried to any point along the way of diminishing returns. The author has attempted to combine fundamental facts with practical discussions in a way to be helpful to the largest number of persons interested in such objectives as better seeing and ideal seeing conditions, and their effects upon human efficiency and welfare. In order not to carry simplification too far the author has depended upon the willingness of readers to meet him part way.

Complex data have been presented in the simplest kind of diagrams. Discussions have been confined chiefly to controllable aids to seeing and to aspects about which something can be done. In many cases readers may wish to delve deeper by consulting original papers; therefore, some references are included. However, more extensive coordinations of the results of researches, and many more references, will be found in two recent books by the author and Frank K. Moss. These are *The Science of Seeing* (1937) and *Reading as a Visual Task* (1942), published by D. Van Nostrand Company, New York.

These works and references reveal something of the effort to ascertain how light and other controllable factors can best serve human beings specifically, and civilized progress in general. For more than three decades our researches have been prosecuted along a broad front encompassing all the external factors associated with vision and seeing. Fundamental factors which influence visibility have been isolated and their relationships established. A much-needed means of measuring visibility has evolved. The old realm of physiological optics was invaded anew and eventually a new realm of physiological effects of seeing was entered. Old concepts had to be extended and new criteria and techniques had to be developed. Light has played its part in a measured way throughout these researches. In the last analysis, all we see is brightness and color, and these are the progeny of light. Therefore, during these decades of research, the relationships of light and vision were systematically studied as never before in continuity and intensity. The result of all this has been the development of much of a new structure of knowledge properly known as the science of seeing.

Among other results, the inadequacy of light and the widespread poor seeing conditions became more clearly evident and the lighting industry awakened to a greater opportunity, and responsibility, to serve. Other industries, theretofore far apart, discovered that they were natural allies in the cause of better seeing. Professions and welfare organizations found new support in their efforts toward the conservation of eyesight and other human resources. About a decade ago, with the lighting industry as a nucleus, a campaign was organized under the banner, *Better Light—Better Sight.*

Born as a slogan for a nation-wide campaign, it rapidly evolved into a world-wide movement. In a decade it crossed the seven seas and invaded the five continents. Founded upon the science of seeing, it touches nearly all civilized activities. Involving the partnership of light and sight, it has attracted a variety of interests. Dealing largely with the essential and generally neglected partner of the priceless gift of sight, it potentially appeals to every civilized human being. It is emphatically concerned with his efficiency, safety, comfort and welfare. Overall, it is helping to combat the widespread indifference to the abuses of eyesight and to the conservation of human resources through better seeing.

In consideration of the variety of interests and the practical objectives to which this book is directed, it seems appropriate to dedicate it to this unique movement,

BETTER LIGHT—BETTER SIGHT

in recognition of a decade of effective endeavor during which it has remained securely founded upon the science of seeing and sincerely dedicated to its objectives.

Notwithstanding its original commercial nucleus and sponsorship, this movement has attracted, and has been greatly aided by, individuals and organizations devoted to human welfare. This is as it should be, for, in a world of private enterprise, the benefits of science reach human beings largely through channels of commerce, involving products and services. This is true whether the product is a vitamin or a lamp, eyeglasses or medical knowledge. This is true whether the service is rendered by an eyesight specialist or a lighting specialist, a profession or an industry. Recognition of these basic facts makes it possible for individuals, organizations, professions and industries, with apparently diverse interests, to combine their forces to promote the efficiency, safety, comfort and welfare of their fellowmen.

MATTHEW LUCKIESH

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In the manufacture of this book, the publishers have observed the recommendations of the War Production Board with respect to paper, printing and binding in an effort to aid in the conservation of paper and other critical war materials.

PLATE I.—Nature first provided light; then eyes evolved to utilize that light. Thus a partnership was consummated eons ago. Nature endowed human beings richly with senses and mind, and a vast storehouse of hidden secrets. Out of the darkness of ignorance, progress has been nurtured by the light of knowledge. Civilization is at once the beneficiary and the trustee of these endowments, and of the knowledge born of them.

CHAPTER I

This Changing World

Among all living things man is uniquely distinguished by his efforts toward self-determination. Originally solely a product of Nature, man transcended the animal kingdom in general because he ceased merely to drift with the current in the stream of Nature. Somewhere in the mists of the past he began to fashion tools and to apply them. Necessity became the mother of invention. Tools multiplied in variety and complexity. The applications of these greatly increased and also the variety and intensity of activities devoted toward self-determination. Particularly in recent centuries civilized human beings by their own achievements have been living in a rapidly changing world!

Necessities are neither absolute nor stabilized. They are relative and they continually multiply with the advance in knowledge and in the elevation of the level of living. Wants increase at a greater rate, and luxuries still more rapidly. There is a perpetual evolution. Luxuries become wants and these in turn become necessities. All these are continually being born of desires for greater production, safety, comfort, ease, convenience and enjoyment. To a great extent necessity and invention are exchanging roles. Now invention often becomes the mother of necessity. And this changing world continually increases the tempo of its change!

No person with normal senses and mind can be entirely oblivious of the enormous change from the natural world of Nature to the artificial, and in some important respects unnatural, world of civilization. That consciousness arises chiefly from the benefits *obvious* to the senses. In the acceptance and enjoyment of these benefits, relatively few persons give serious consideration to the new problems created by change or to the possible penalties arising from this changing world. Most of these are unobvious, often hidden deeply in statistics or even more deeply in the realms of health and life processes. These penalties may be exacted remotely from the cause and even remotely in time. Even professional practices based upon modern science too generally ignore the possibility of deleterious effects of the great changes which man has wrought in his environment and in his activities. Busy with the consequences, little time is available to devote to causes. Relatively few are paid for studying, reducing or eliminating causes. Even modern science is sometimes slow in recognizing the need for studying the hidden effects of change and the need for development of corrective measures or compensating expedients. Nevertheless, research is just as necessary for *remodeling* man's artificial world as endless research is essential for the continual *building* of it.

ENSLAVED BY NEAR-VISION

On every hand man has accomplished much in easing the burdens of human muscles. Electrical energy in the past century has done much to transform working and living. Much arduous work has been shifted from men to motors. In uncounted ways electricity provides obvious benefits in comfort, ease, convenience and enjoyment. But while these obvious benefits have come to civilized human beings, man's skill and knowledge have greatly increased. As a consequence, tools and tasks have greatly multiplied.

Owing to the dominance of the visual sense in the usefulness and activities of human beings, visual tasks have multiplied enormously in number, variety, duration and severity. Seeing has assumed unobvious burdens as well as obvious responsibilities. And in this changing world no more complete and universal change has taken place than from distant-vision and casual seeing in the natural world outdoors, to the oppressive slavery of near-vision and critical seeing in man's artificial world of civilization. This is an important change indeed! And one outstanding gift of the electrical age—efficient, convenient, controllable artificial light—can do much to ease the burdens upon human eyes and the entire human being.

In the past few centuries, a relatively brief period even in the evolution of human eyes and human beings, civilized mankind has been thrust into a world of near-vision. Countless tools and tasks are within arm's reach. Critical visual tasks, which require accurate convergence and accommodation of the eyes for prolonged periods, are severe unnatural tasks of seeing. Some of the penalties of this great change in the use of the eyes are more or less obvious. Some known ones are not obvious. The matter justifies serious consideration in various professional practices dealing with the eyesight, health, safety, efficiency and general welfare of human beings. Certainly only through extensive tedious research may we ascertain how various aids to seeing ease the tasks of seeing. Much knowledge is already available but only a beginning has been made in directing it toward easier seeing.

It is important to ascertain and to utilize the contributions which various aids to seeing may make toward easier seeing. Man has made great strides away from Nature. A general retreat is scarcely possible against such forces as the trends of civilization. But easing of the tasks of seeing is possible and desirable. The same method—the continual application of new knowledge—which has constructed man's world, will reduce the burdens of seeing and may eliminate certain penalties of change which accompany the benefits of change. But the great changes in environment, in the use of eyesight, in the responsibilities of seeing, and in the severity of modern tasks of seeing must first be recognized and adequately appraised if advances toward easier seeing are to be achieved on the broad front of civilized progress. And real progress is more a matter of advances in human welfare through conservation of human resources such as eyesight, energy, health and life of human beings than of mere advances in obvious comfort and convenience.

ADAPTATION IS SLOW

Evolutionary processes are too slow to adapt eyesight and human beings to the relatively sudden enslavement by near-vision. There is overwhelming evidence of this throughout Nature and there are some specific facts pertaining to vision. For adults possessing socalled normal vision, visual acuity, or the ability to distinguish fine details of threshold or barely visible size, is measurably greater for distant-vision than for near-vision. In general the visual sense operates most efficiently, not only from a muscular viewpoint but from a purely optical viewpoint, when engaged in distant-vision. This is an indictment which hangs over near-vision throughout the entire adult life-span. In view of the imperceptibly changing processes of evolution, these fundamental facts in favor of distant-vision may be expected to persist for many generations notwithstanding the enormous increase in the use of the eyes for prolonged periods of near-vision during the past few generations.

With the processes of evolution ever at work striving to adapt living things to their changing environment, it is probable that the eyes of civilized human beings will eventually develop so as to function more effectively and more easily for near-vision. In addition, it is conceivable that our present enslavement by near-vision will be diminished eventually as machinery continues to replace human effort. Such developments as motion-pictures and television may replace near-vision tasks to some extent. However, adaptation by the processes of evolution is of little practical aid or interest to us now. Therefore, it is very important to realize that in a relatively short time the uses of human eyes and the tasks of seeing have changed from easy, casual natural ones to relatively critical prolonged unnatural ones.

One aspect of changes in eyesight due to usage may be of more importance than strictly evolutionary changes of the past. This deals with environment and heredity, the scientific analogue of the chicken-and-egg dilemma. Heredity traced backward far enough resolves itself into the accumulative effects of past environment. One can scarcely avoid the conclusion that eye-defectiveness, and probably other unobvious effects, are to some extent the result of abnormal present usage and environment. On the other hand some eye-defects appear to be inherited. Therefore, it is possible that through heredity some of the penalties of abnormal abuse or unnatural use of eyesight under generally poor seeing conditions are passed on to future generations before evolutionary processes adapt human eyes and human seeing-machines to the new tasks of seeing imposed by modern civilization. If this is true, progress toward easier seeing becomes of importance even beyond the present. Probably we may have to add to the folly of abusing ourselves and our eyesight an unforgivable abuse of generations as yet unborn.

LEARNING TO SEE

Human beings must learn to see just as they must learn to use their legs and hands to do other things. For example, the reader of these printed words sees them out in space. The images of these words are actually focused on the retina of each eye. If the optical system of the eyes is normal, the images produced by the two eyes, respectively, properly fuse. Then the reader apparently sees these printed lines out in space where the page and other things actually are. By means of other senses, combined with the subtleties of binocular vision, one has learned to see.

Learning to see takes place at an early age and the successes and failures are not as obvious as those of learning to walk, for example, with the result that this period is not generally adequately considered. Human eyes evolve physically for some time after birth and faculties such as orientation, accurate fixation upon objects and complete binocular vision or fusion of the retinal images are gradually acquired. Some believe that these visual processes are fully developed at the age of six years, but others, at least with greater safety, maintain that these mechanisms and faculties continue to develop long after that period.

Certainly a normal baby is born with many endowments. A long period of infancy and a still longer childhood are necessary for the development of the necessary faculties and abilities for utilizing these endowments. Certainly a long period is required for developing the complex automatic functions of vision and seeing. It is difficult to believe that these can be perfected before the even more complex neural and mental processes have reached a high state of development.

EYESIGHT AND NEAR-VISION

There is no well-defined borderline between near-vision and distant-vision. When objects are viewed at a distance of twenty feet or more, the eyes are considered to be engaged in distant-vision. When viewing objects at such distances the strain upon the eye-muscles, which control the lenses in accommodation (focusing upon the object) and the two eyes in convergence (upon the object), is minimized for socalled normal eyes. As the distance of the visual object or task diminishes, the strain upon the eyes and upon the entire human being increases. When objects are viewed within arm's reach, the eyes are said to be engaged in near-vision. For example, reading is commonly done by adults, possessing normal vision or proper corrective glasses, at a distance of approximately 14 inches. This is generally considered to be the normal reading distance for adults but such a term is confusing.

In an absolute sense there is no normal distance for near-vision. The acquisition of particular skill with the hands has resulted in bringing most of the tasks of critical seeing within arm's reach. Civilization has wrought no greater change than creating a world of prolonged critical seeing of things and tasks within the unnaturally small world measured by the length of the arms. Adults with socalled normal vision usually possess some reserve in accommodation until they approach the bifocal age when presbyopia begins to become apparent. Then eyeglasses are necessary so as to provide some reserve or range in the ability to accommodate; that is, to focus the eyes upon the task. Thus for most eyes the performance of the tasks of near-vision with the aid of glasses does not produce the maximal strain but this result is approached. At any rate the strain upon the eyes and upon the human being is incomparably greater for near-vision than for distant-vision. (See Chapter XVII for definitions of terms.)

Having shorter arms than adults, young children naturally hold the task, such as a printed page, closer to their eyes than adults do. However, they generally possess a greater reserve in accommodation and convergence which makes it possible for them to see at these lesser distances. The eyes of most babies and very young children are somewhat farsighted (hyperopic). Apparently this condition is generally due to the fact that the eyeballs are not spherical but are somewhat flattened along the axis of sight. This deficiency is normally overcome in the process of growth. Thus during early childhood, rays of light from a distant object would generally be brought to a focus behind the retina if it were not for the fact that accommodation comes into play. This necessary increase in the power or convexity of the eye-lenses moves the focus forward so that the image of the object falls upon the retina. Thus even distant-vision in early childhood involves strain in certain eye-muscles, an abnormal expenditure of muscular effort and other effects. Obviously an even greater expenditure is involved in near-vision.

When it is difficult to see details, such as printed matter in reading or fine thread in sewing, the tendency is to bring the task closer to the eyes or the eyes closer to the work. For example, if the type is small or the illumination is low or the lighting is glaring, the only recourse is to bring the eyes and task closer, thereby increasing the already greater strain due to near-vision. It is easy to believe that poor seeing conditions, due to inadequate light and improper lighting, are responsible in part for the relatively high percentage of eye-defectiveness among garment workers, for example.

YOUNG AND OLD EYES

Critical tasks of near-vision are imposed upon children at an early age in relation to the period of years required for complete development of visual mechanisms, functions and faculties. When one considers the abnormally critical and unnatural near-vision tasks which civilization has imposed upon human beings, the statistics of defective vision have more meaning. Particularly the rapid increase in nearsightedness (myopia) among children as they advance in school suggests the possibility that educational achievement may be purchased, partially at least, at the expense of eyesight or ocular welfare. At any rate, such considerations indicate that near-vision tasks should be minimized during childhood and that all aids to seeing should be provided for children when and where they are required to perform near-vision tasks for extended periods. Large print and adequate light may, along with proper encouragement, reduce the tendency for young children to hold a book too close to the eyes. But the fact still remains that their arms are short. Therefore, it appears well worth while to utilize distant-vision more, as in some phases of socalled visual education. Furthermore, systematic eye-exercises might well be widely considered.

Apparently due to the hardening of the crystalline lenses, most persons arriving at middle age find it difficult or impossible to see nearby objects distinctly. This means that the eyes are no longer readily able to focus accurately upon the retina the images of objects within arm's reach. This condition known as presbyopia begins almost universally at middle age and continues to increase with age. The cause of the hardening of the eyelens with age is not known. It may be possible that the infinitely greater use of accommodation for near-vision than was the case during ages of evolution of the human race may have something to do with this relatively premature deficiency of the visual mechanism. Fortunately, eyeglasses compensate for this inadequacy of accommodation but, of course, they do not deal with the cause. They are very useful crutches but the eyes remain defective nevertheless.

It is seen that in two long periods of the life-span the eyes are not particularly well adapted to near-vision. In the case of young normal eyes, which are generally farsighted, near-vision calls upon accommodation abnormally. In the case of eyes past middle age, which also are generally farsighted, satisfactory near-vision is commonly impossible without eyeglasses because the eyes have lost much of their power of accommodation. The obvious difficulty or impossibility of focusing middle-aged eyes upon objects within arm's reach leads to the use of convex glass lenses to supply the additional dioptric power to bring the focus of the image from behind the retina to its proper place on the retina. During childhood accommodation reserve is such that this additional dioptric power may be supplied by increasing the convexity of the eyelenses themselves which are still sufficiently resilient. From these viewpoints, in early childhood and the latter half of the life-span, one may reasonably assume that the performance of critical near-vision for prolonged periods is a particularly unnatural and abnormally severe activity of human eyes and of seeing. Normal eyes are entitled to every reasonable aid to make seeing easier. Young, old and defective eyes are entitled to aid even more so.

EYESIGHT AND SEEING

A lathe possesses a cutting tool with which useful work is done. But behind this tool is a complex machine which drives, supports and guides this tool so that the specified task is accomplished. Even when the tool and the machine are not overburdened with work more strenuous than that for which they were designed, there are strains and energy losses and a certain amount of wear and tear. Eventually repairs are necessary but with proper use the machine does its job satisfactorily. However, abuse produces obvious damage not only to the cutting tool but to the machine behind it. And all the time useful work is associated with the *tool* and useless work is done by the *machine* in overcoming friction and other wastes of energy. This useless work and the abuse of the machine and of the cutting tool increase with negligence. Conversely they decrease if the work done is not too severe and if the available aids are applied to the machine and its cutting tool.

Oil eases the work done by the machine and prolongs its life. But machines can be repaired and even replaced. The repair of eyes is extremely limited and they are not replaceable. In performing a task of seeing, eyesight is analogous to the tool and the entire human being is the machine. Light in one sense is analogous to the oil supplied to machines. Some is absolutely essential. More light leads toward easier seeing. Adequate light results in easiest seeing and minimizes the burdens of modern seeing, if other specific secondary aids are also fully utilized. As in the case of oil, adequate light should be applied in the proper places. Both oil and light can be unwisely used. Wear and tear and wasted energy are to be expected even when performing tasks of seeing under the best conditions. To minimize these should be the aim of those who supply and control various aids to seeing.

The foregoing analogy would be fairly complete excepting that the machine behind the eyes is a *human* machine with human vagaries and reactions, with nerves and mind. As a consequence, unnecessarily low visibility and severity of visual tasks, inadequate light, distractions in the visual field, such as glare, and distractions through any of the other senses decrease the ability of the visual sense and increase the waste of human resources or the useless work done by the human seeing-machine. This extended concept of seeing is particularly emphasized because its full import must be grasped if the manifold aspects of seeing are to receive adequate consideration.

Abundant statistics reveal appalling percentages of defective eyes. Many visual defects would be ignored or even unnoticed were it not for the fact that many modern tasks of seeing are performed under near-threshold conditions; that is, under conditions of barely seeing. Examples are to be found everywhere due to a combination of small details, low contrasts, insufficient light and improper lighting. Such tasks become even more difficult as the eyes and the human seeing-machine become fatigued from excessive periods of critical near-vision. Thus many unobvious deficiencies become manifest and the assistance of eyeglasses is demanded. However, many persons wearing eyeglasses could dispense with them if tasks of near-vision did not have to be performed. Furthermore, it is a fact that more light and better lighting generally aid defective eyes even more than normal eyes.

Eyestrain commonly results from uncorrected defective vision but it may possibly be a cause as well. It also arises from poor seeing conditions. It leads to fatigue of eye-muscles and it is a commonplace fact that defects and failures of materials are often born of fatigue. Certainly strain and fatigue of eyes are far greater for near-vision than for distant-vision. Actually, in order to focus and to converge the eyes upon reading matter at the common reading distance, considerable amounts of accommodation and convergence (about three diopters) are required while distant-vision is performed with approximately relaxed accommodation and almost no convergence of the two eyes. It may be significant that the ophthalmologist describes these muscular states of the eyes as dynamic and static, respectively. It is also revealing that it is often much more difficult to prescribe satisfactory corrections in eyeglasses for near-vision than for distant-vision.

THE HUMAN SEEING-MACHINE

Serious as they are, eyestrain, eye-fatigue and eye-defects are not the only effects or penalties of seeing. These are associated only with the eyes which are analogous to the cutting tool of the lathe. Behind the eyes, operating them and performing the tasks of seeing, is the human being, or more specifically, the human seeing-machine. Excepting for certain aspects of health and disorders caused or aggravated by eyestrain, the human being as a seeing-machine has been too generally ignored. We have found some effects of seeing to be deep-seated and distributed throughout the human organism. It is possible that consequences may result from some of these effects, but only a sound beginning has been made in the exploration of these effects remote from the eyes. However, the results of researches have already established the extended concept of seeing and have opened vistas of new considerations of human welfare in our modern world of unnaturally critical and prolonged tasks of near-vision.

Many examples can be cited which demonstrate that we perform a task of seeing, not merely with our eyes, but with our muscles and nervous system, our body and mind. Try holding the sights of a rifle on a very small target. In a few seconds one is conscious of strain and tenseness pervading his entire body or being. In a minute or two the task may become nerve-racking. Rest the rifle so that there is no muscular effort devoted to supporting it. The strain is still obvious and pervades the entire being as the minutes pass. Sighting a large target is obviously much easier on the eyes, body and being.

In performing common critical tasks of seeing the effects are similar but they may not be so obvious in many cases. There is much more strain in keeping the eyes "sighted" on a line of fine print than on large print. This is true if for any reason it is more difficult to see in one case than another. When the strain is not too obvious it goes unnoticed but its accumulative effect over a long period is fatiguing at least. We have as much right to extend "labor-saving" devices and conditions to seeing tasks as to other tasks.

Long ago such reasoning led the author to invade this intricate realm of physiological effects of seeing in order to ascertain the possibilities of various aids to seeing, including light and lighting, in making seeing easier. The results of many researches[1] are discussed in Chapter XIII. Here it is sufficient to state that various more or less hidden effects of seeing have been definitely revealed. For example, more light and better lighting within certain limits reduce the fatigue of the eye-muscles of convergence. They also decrease tenseness which pervades the muscular and nervous systems. Good seeing conditions maintain the heart-rate more nearly normal. Through many researches whose results correlate into a formidable and apparently consistent structure, the rate of involuntary blinking has been revealed as an indicator of ease of seeing. With these physiological effects of seeing, and particularly the blink-rate, various controllable aids to seeing have been studied. Much has been learned about making seeing easier by various means such as wearing correct eyeglasses, increasing the level of illumination, decreasing preventable glare in lighting, eliminating dark surroundings, increasing the size of type and other critical details of visual tasks when possible, and by various secondary aids.

In general, seeing has been adequately proved to be far more than vision; and ease of seeing has been revealed as an important concept which should have as much attention as eyesight. Seeing is decidedly an activity of the entire human being. It utilizes human resources beyond the eyes. Of great practical importance is the revelation that one cannot appraise seeing conditions with any degree of dependability, excepting when they are extremely bad or good. Considering the deep-seated effects of seeing, any other viewpoint is untenable. We do not attempt to judge by mere observation the weight of a roast of meat or even temperature or humidity. We have devices for those purposes which aid our senses. The physician and the eyesight specialist depend upon the sciences which dictate their practices and upon the devices developed for their needs. So it is with seeing and with the aids to seeing and particularly those universal ones—light and lighting. Modern civilization needs seeing specialists to diagnose seeing conditions and to prescribe the means for making seeing easier. Seeing specialists can play a great part in human efficiency, safety, comfort and welfare.

CHAPTER II

Appalling Prevalence of Eye-Defects

Eye-defects as discussed in this book are those of the common refractive type which are correctable or at least aided by eyeglasses. Pathological conditions in the narrow sense of the term are entirely excluded. In other words, eye-troubles or conditions that are solely within the province of the medical practitioner are not included in this discussion. The purpose of introducing eye-defectiveness at this point is not merely to reveal the appalling percentages of defective eyes. Such eyes need even more help from various aids to seeing than normal eyes do. This should be kept in mind throughout succeeding chapters which, unless specifically stated, provide data and recommendations for adults with socalled normal vision.

Much of the aid which can be given to eyes by making seeing easier is beyond the practice and daily interest of eyesight specialists. They have not specialized in much of the knowledge and practice upon which easier seeing depends. Few of them follow eyes into the world of seeing with its countless tasks and conditions of seeing. Eyesight specialists care for the eyes as tools and "sharpen" them with glasses. Eyeglasses are great contributions of science for the many persons who need them. They compensate defects in the optical system of the eyes and reduce eyestrain. They are excellent and essential aids to seeing, but they neither reach nor compensate for other conditions which conspire to make seeing difficult. With unconscious irony, the increasing percentage of persons wearing glasses is sometimes hailed as proof that more persons are paying attention to their eyesight!

Excellent progress has been made in some directions in the conservation of vision. Preventive measures are taken at birth by disinfecting babies' eyes. Periodically, air-guns and fireworks

Plate II.—Eyeglasses are a boon to that large, and apparently increasing, percentage of us who need them. We are justly thankful for the knowledge which creates and supplies them. But are they to be accepted as an inevitable distinction of a civilization which has greatly increased the burdens upon human eyes? Viewing the widespread prevalence of eye-defectiveness, are we satisfied with our trusteeship of such a priceless endowment as eyesight?

are condemned but are still available and legal in many places. Safety measures are prescribed in industry. But most common eye-defects are not the result of accident. They are accumulated in the ordinary course of time and to some extent at least in the common use and abuse of the eyes. How much this can be prevented is not known for no adequate long-range investigations have been made. No profession or organization has been adequately concerned about the common eye-defects of the refractive type.

EYE-DEFECTIVENESS

Imagine we are standing on a street corner watching the noon-day flood of humanity temporarily freed from the shackles of more or less exacting and prolonged use of their eyes. Soon most of them will return to their work-world tasks to which their eyes will be shackled again, like galley slaves. Suppose that suddenly half of these human beings began to limp, that many used canes, that others hobbled on crutches and some were in wheel-chairs. That would be the appalling spectacle, if eye-defects were momentarily transformed into leg-defects. Change the scene to a college campus or a garment factory. In one case about a third would be limping and in the other, more than two-thirds. Most of these eye-defects are well served by eyeglasses—and both are too generally accepted as inevitable! Certainly this is not the attitude which has advanced human welfare so markedly in many ways.

About one person in every five of our entire population wears glasses. Twenty-five million persons in this country with eye-crutches! The eyes of another twenty-five million with eye-defects are more or less limping along without crutches. A total of fifty millon—forty percent of our entire population—has appreciable defects of vision of the refractive type. Worse still, an attitude of prevention is relatively non-existent in an age in which preventive measures have made enormous strides in medicine, surgery and elsewhere.

Medical journals and reports of welfare organizations for many years have revealed appalling statistics of eye-defectiveness.[2]

They may be condensed into three interesting categories which provide much food for thought.

1. Nearly all our babies—apparently an average of 95 percent—are born with nearly normal vision. Actually they are farsighted, but this appears to be a matter of incomplete development of the eyes at birth. At least most of us still begin life with reasonably normal eyesight. This is encouraging.

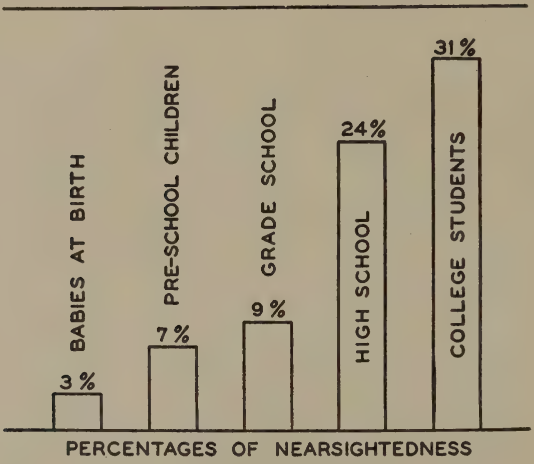


FIG. 1.—The rapid increase in nearsightedness with age in schools and colleges should be a challenge. There is no evidence that it is inevitable and there is some evidence that it is, at least, partially preventable.

2. Eye-defects increase markedly with age. Only a few percent of children entering school have eye-defects of the type for which eyeglasses are prescribed. Eye-defects, such as nearsightedness, increase rapidly from grade to grade as seen in Fig. 1. About one out of every four has measurable eye-defects at graduation from high school. This ratio increases to nearly one out of three when young people are graduating from college. Eye-defectiveness increases to fifty percent at middle age and to about eighty percent at an age of sixty years as seen in Fig. 2. Even presbyopia, which begins to be evident at middle age—when this page can no longer be read at the usual distance—cannot rightly be accepted as entirely inevitable without proof. The lenses of

the eyes lose some of their elasticity with age. Is this natural or can it be due in part at least to excessive performance of tasks of near-vision during which the eyelenses are in a strained state of abnormal convexity?

3. Eye-defects vary markedly with occupation. The percentage of eye-defects is less for outdoor workers than for indoor workers. It is less among farmers than librarians. A typical investigation [2] reveals that seventy-five percent of garment workers had some defect of vision. This is far above the average for the entire population. The greater prevalence of eyestrain troubles and eye-defects in occupations where the tasks of seeing are obviously severe is a strong indication that the magnitude of eye-defects and possibly their number are preventable to some degree. This is emphatic evidence that they are partially the result of our use of the eyes and perhaps of poor seeing conditions which generally can be greatly improved. In Fig. 3, a generali-

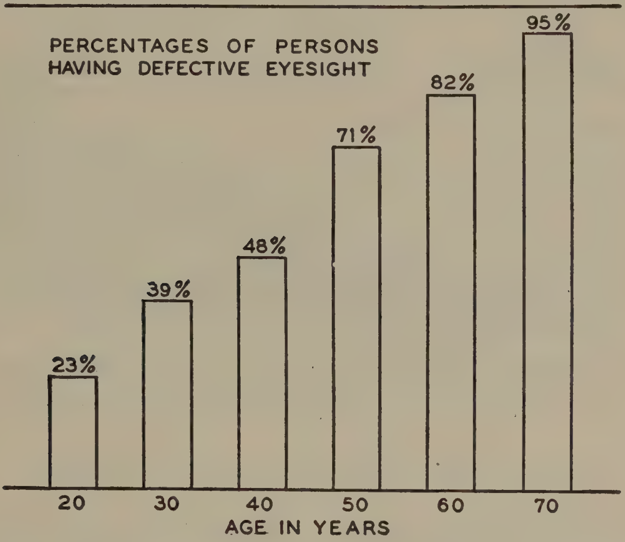


FIG. 2.—Eyesight defectiveness increases markedly with age. Instead of accepting this, more consideration should be given to the widespread use and abuse of eyes in performing the unnaturally prolonged and severe tasks of near-vision in our artificial world of civilization.

zation adapted from a summary published long ago by Gould,[3] provides food for thought—and action.

There is evidence that eye-defects are more prevalent now than they were a generation or two ago. Statistics gathered thirty years ago[4] showed that nearsightedness in school-children was less in schools where the seeing tasks were less severe and the seeing conditions were better than in other schools. These facts have made no adequate dent in the general complacency and indifference.

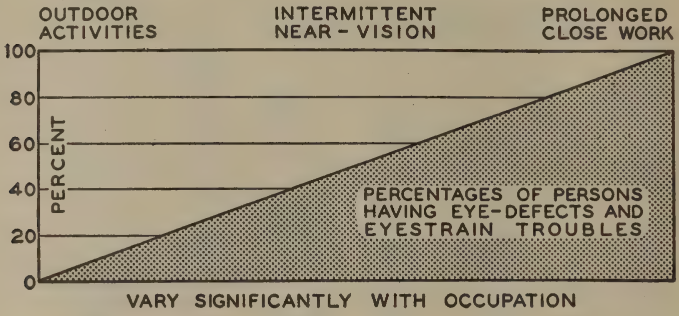


FIG. 3.—A diagrammatic view of the greater prevalence of eye-defectiveness and eyestrain troubles in occupations involving prolonged critical tasks of near-vision.

The following quotation is from a recent excellent paper[5] in a leading ophthalmological journal reporting the results of an intensive investigation: "Forty-three percent of the population reported ocular discomfort or inability to see clearly at all working distances. Approximately seventy percent of the complaints involved headaches, eye-aches, blurred vision, tearing and burning."

These results were not obtained in a backward distant land or among the poor and neglected in our own country. They were not the results of examinations of sweat-shop workers enslaved by a totalitarian government. They summarize the results of elaborate eye-examinations of 126 pupils—the entire fifth-grade population of an average public school in an eastern state. These fifth-grade children were about ten years old, but no profession or organization appears to be adequately awakened and concerned about such revelations.

The investigators quoted in the foregoing paragraph recorded appalling facts with no indication that the facts were appalling to them. They conclude that "if the findings herein reported were verified by subsequent studies, then serious thought should be given to preventive measures." What further verification or thought is needed? Time marches on!

This intensive survey illustrates an almost universal complacency in regard to a very serious matter. Eyeglasses are available, if needed eventually, and one wonders if this fact does not help—falsely—to soften the blow of statistics. The report which was published in a leading scientific journal contains only a vague suspicion of possible causes and no hint of possible preventive measures. Nothing was said about the level of illumination or the kind of lighting which are universally important in seeing tasks and conditions. These should be of particular concern in schools where seeing habits are formed and where eyes are scarcely mature in growth and in function.

EYESIGHT IN WORLD WAR II

If normal or near-normal vision without eyeglasses had been a universal requirement for service in the armed forces in World War II, about one-third of the men in the draft-age group would have been rejected solely on account of eyesight. In order to recruit a sizable army, privates were admitted if their vision was as low as 20/100. This means that they had only to be able to read a line of letters at a distance of 20 feet that they could have read at 100 feet if they possessed normal vision. Interpreted in another way, it means that they could barely recognize letters on the test-chart that are five times the size of the smallest letters that can be distinguished by persons with normal vision. Their visual efficiency is only 50 percent according to the A.M.A. rating discussed in Chapter XI. Viewed in still another way, persons with 20/100 vision are well along the road to blindness which, for legal purposes, has been defined as 20/200 vision. In other words, if a person can barely distinguish letters 10 times the size of the minimum for normal eyes—or can barely read letters at 20 feet that normal eyes can read at 200 feet—he is legally blind in various countries.

To be admitted as privates into the army, the eyes had to be correctable with glasses to 20/40 vision. In other words, with glasses they had to be able to read letters twice the minimum size for normal vision. Even with this low standard of vision without glasses, the rejects for this cream-age draft-age group amounted to several percent. Indeed we are, in large part, a nation of eye-cripples.

The Air Corps required socalled normal vision without glasses and the Navy's requirement was also high. Thousands of young men can blame their eye-defects for their failure to realize their hopes and ambitions in the armed services. Many of us knew one or more of these disappointed young men.

Incidentally, the indifference to light as a partner of sight was exemplified in the eye-examinations for the armed services. Only rather crude specifications were available for illuminating the test-charts. Some borderline cases found that they could pass the visual-acuity tests in one place and not another, depending upon the lighting conditions. For accurate eye-examinations of an adequate nature for revealing the visual efficiency of subjects for the tasks of our world of seeing, the illumination of test-charts and the brightness of test-fields must be standardized. These aspects are discussed in Chapter XI.

LONG-RANGE INVESTIGATIONS NEEDED

Eyeglasses are definitely a badge of civilization. Are they badges of valor, or ignorance, or indifference or neglect? Can the increase in eye-defects with age be diminished or even halted? Can their overwhelming prevalence in certain occupations be reduced?

We cannot make guinea pigs of human beings and deliberately risk their eyes in strenuous experiments which purposely damage eyesight. But this is unnecessary. All civilized human beings automatically become guinea pigs in this artificial world of unnaturally prolonged and critical tasks of near-vision. Statistics already reveal some facts. With proper planning they would eventually reveal the possibilities of preventive measures. Long-range records over many years could be obtained on a large scale in schools and in the work-world under conditions which could be adequately appraised and described. These should begin now if we are really interested in the eyesight of posterity or even of our children who will comprise the next adult generation. It would be interesting to note the effect of good lighting and seeing conditions upon the percentage and character of eye-defectiveness. There is some encouraging evidence.

There is also encouragement in a commonsensical approach. With our eyes evolving for uncounted eons, is there any reason to believe—or even to assume—that they should not grow old as leisurely as the rest of our bodies? Should they begin to become defective in early childhood? We have no right to assume that the rapid increase in the percentage of eye-defects among children after entering school is entirely natural or inevitable. That assumption requires just as much proof as an assumption that the unnatural use of the eyes in the prolonged performance of near-vision tasks under poor seeing conditions may be a cause of eye-defects. And there are some indications of the latter.

At this point the reader might well ask what are the causes of the common eye-defects. Initially, it is not necessary to ascertain the causes. In fire-prevention the conditions favorable to fires are recognized and they are reduced or eliminated if possible. As a result fires are not entirely eliminated but they are reduced in number. If agencies already at work in some phases of eye-care would expand their viewpoint and knowledge to include the intimate details of visual tasks and of seeing conditions that are unnecessarily burdensome, a decisive beginning would be made.

It is high time for us to become excited over the shocking prevalence of eye-defects. We have a right to expect the attention of institutions devoted to human welfare. We owe this to ourselves and to our children. We owe to posterity good eyesight more than many things about which politicians prattle. We are confronted with the striking fact that civilization has enormously increased the burdens upon human eyes and has done relatively little toward counter-measures. There are many ways to decrease these burdens. It appears probable that the prevalence of crippled eyes can be reduced. If it cannot be halted, we are traveling the road toward blindness. Certainly it is our responsibility to try our best. And in doing so we will receive immediate dividends in lessened strain and fatigue just as these are lessened when physical tasks are made easier.

No other parts of civilized human beings, with the exception of teeth, exhibit such early and general defectiveness as eyes or eyesight. Some of the deterioration of teeth is attributed to their use under abnormal or unnatural conditions. The inherent character of civilized foods has received some attention. The change from coarse natural foods to softer, refined and cooked foods is considered to be at least a partial cause of defective teeth. The use of the eyes for prolonged critical near-vision tasks is an interesting parallel. It also supports the view that orthoptic exercises may be properly prescribed for the eyes just as various methods of mechanical stimulation of the teeth are advocated for simulating the exercise which would be obtained by eating coarse natural foods. Such considerations readily lead toward the conclusion that certain eye-defects and even eyeglasses are often placards indicating abuse of the eyes through unnatural use and under poor seeing conditions for prolonged visual work.

RESPITES AND EXERCISES

The strain of holding the sights of a rifle on a small target is obviously greater than when the target is large. If one is not familiar with the strain of target-practice he might try threading a needle. The eye of a small needle is a small target. Try threading it repeatedly for only a minute or two. Then note the relief when a large needle is substituted. In both cases the strain is obviously greater when the seeing conditions are poor than when they are good. Note particularly that the strain is not confined to the eyes but pervades the entire human being—throughout muscular, neural and mental realms.

Many of our tasks of near-vision involve keeping the eyes and mind carefully focused for long periods upon details which are difficult to see because they are small or of low contrast with their backgrounds, or because the light is meager or the seeing conditions are generally poor. In reading this text all day long the eyes must travel with careful fixation—muscles and nerves and mind doing the focusing—over a line of type a mile long. Respites are few and unplanned at best. Now spill some ink on this page and let it dry. Imagine trying to read this print on the dark background for hours daily. Such a task is illustrative of sewing on dark goods and many other visual tasks. The visibility of these tasks is relatively low. The strain on the eyes is greater—and it is increased by a tendency to hold the work closer to the eyes. The Visibility Indicator on the inside of the back cover of this book illustrates the foregoing tasks.

Besides making the tasks of seeing easier by all possible aids, the possibilities of systematic eye-exercises have been too generally ignored. Mere mention of these has made most eyesight specialists shudder, for exercises have been advocated as a cure-all for all kinds of eye-troubles and defects. The socalled Bates method has acquired a following, but the unscientific attitude and claims of some of its proponents have not aided its standing. One may view eye-exercises with common sense without accepting them as a cure-all. It appears just as sensible to exercise the eyes as to exercise the arms, legs and body. Systematic exercises, particularly involving distant-vision—even ten or twenty feet—are worth trying. Medical supervisors of schools might well initiate these. They might even be extended to the adult work-world in offices and factories where prolonged near-vision tasks predominate. They could easily be practiced by all of us even at home. A do-nothing policy is far worse than appeasement with eyeglasses.

In schools, eye-exercises might well be an inconspicuous part of socalled visual education which has been promoted largely on a pedagogical basis. Large charts and pictures projected on the front wall of a classroom provide respites from the shackles of near-vision. It would be interesting to note statistically the effects of such respites and exercises if they were systematically provided often enough and prolonged enough, during the entire sojourn of children in public schools. Eye-care has made so much progress in certain directions that the indifference to other measures of probable preventive value, such as systematic exercises, respites from near-vision, good lighting and generally better seeing conditions, is somewhat surprising if not actually appalling.

In an age in which prevention is in the ascendency, common eye-defects will not continue to be accepted as inevitable and seeing tasks are bound to be made easier. These will be a natural result of a broadening of a seeing consciousness beyond its present narrow limits. Certainly such matters are deserving of as much attention as has been devoted to the perfection and prescription of eyeglasses. These suggestions are not made with any intention or hope of eliminating the need for eyeglasses, which are indeed a boon in the age of prevalence of eye-defects and of critical tasks of near-vision. There is only the hope that the progress of magnitude and prevalence of eye-defects might be somewhat restrained. At any rate, progress toward easier seeing would be a worth-while reward.

Plate III.—Light aids sight in accordance with the knowledge and care exercised in its use. Measurements of visibility reveal the effects of background, of shadows and highlights, of various levels of illumination, and of the position and extent of supplementary lighting. Visibility and ease of seeing cannot be appraised by mere inspection or introspection.

CHAPTER III

Light and Sight

The two essential tools for seeing are light and vision. Normal eyesight or socalled normal vision has certain inherent abilities. Under fixed conditions these abilities become limitations. Certain aids to seeing such as a magnifying glass, a microscope, a telescope, light and lighting can extend our ability to see. Light is the omnipresent aid which can be called on for more help. It is not only as essential as vision but it can greatly extend the abilities of its partner—sight. However, throughout the development of the science of vision, light has been generally neglected. At best it has been considered as an incidental or secondary factor instead of a full partner as it well deserves to be. In fact, light and lighting afford the only universal means of progress toward easier seeing.

Eyesight specialists practice their knowledge of vision largely in their offices. Ophthalmology has made enormous strides in eye-care, eye-treatment and eye-surgery. Both the ophthalmologist and optometrist service eyes with glasses but their practice does not include following eyes out into the world of countless visual tasks. Their primary interest is in vision, not in seeing. To understand seeing requires a considerable extension of the interest, knowledge and techniques of eyesight specialists into the realms of visual tasks and of various aids to seeing. The eyesight specialist is paid for caring for eyes and for prescribing eyeglasses. Rarely is he paid to follow eyes into the world of use and abuse. Besides, his techniques, excellent as they may be for his purpose, are inadequate for prescribing light and secondary aids for the countless tasks of seeing.

Obviously we civilized human beings are not going to give up our artificial indoor world and return to outdoor pursuits. We will continue to perform the artificially severe and unnatural tasks of near-vision—reading, writing, sewing, drafting, engraving, inspection and countless others—for long periods daily for a life-time. We will do this as long as our eyes can be adequately served by eyeglasses. But we will read less and listen to the radio more as our vision depreciates. That is inevitable.

In all the manifold tasks of seeing, light is essential; but even though it is an essential partner of sight, it has been relatively ignored. Generally it has been taken for granted. Levels of illumination indoors—supplied by daylight or artificial light—generally bear little or no relation to the character of the visual task being performed. A low level of illumination which may be sufficient for casual reading of black print on white paper is not adequate for prolonged reading. Of more importance is the fact that sewing on dark goods, and many other tasks involving fine details, low contrasts and poor reflection of light, require many times more light than reading this black print on white paper, if visibility or ease of seeing is properly considered. The character of the lighting as well as the level of illumination is also of great importance. Lighting is generally ignored even more than light. Many factors which affect seeing can be measured and light and lighting can now be scientifically specified for various tasks.

NEED FOR SEEING SPECIALISTS

In our civilized world, so overwhelmingly engaged in seeing tasks upon which the efficiency, safety, comfort and welfare of human beings depend, there is as yet no profession of seeing specialists. Eyesight specialists, with relatively few exceptions, must necessarily limit their outside activities to a generous interest in human welfare. They are paid to take care of vision chiefly in their offices. In general, they do not deal with the countless visual tasks and variety of seeing conditions in our everyday world of seeing. Some individuals and organizations extend their activities to specific aspects of the conservation of vision through safety, hygiene and welfare channels. None deals adequately with seeing as the most universal activity of human beings.

With the great advances in the production and control of artificial light and the recent rapid development of the science of seeing,[6] lighting specialists, and the various components of the lighting industry, awakened to new opportunities to serve civilization with adequate light and proper lighting. Much of the research which has established the relationships of light, vision, lighting and seeing has been prosecuted in the laboratories of industry. This is natural and requires no explanation or apology.

Manufacturers of drugs, and also members of the medical profession, prosecute researches in the fields to which their products and services, respectively, are applicable. And they get paid for their products and services. These are natural procedures in the kind of a world we live in, where products and services are paid for by the beneficiaries. These are among the privileges and responsibilities of private enterprise which has given the world radios and other marvelous products of electronics, X-ray machines and miraculous drugs. The source of beneficence is of no consequence. The fields of research concerned with human welfare are always open to any individual, profession or organization. There is no monopoly in the search for knowledge.

The foregoing is just as true—and as natural—where the various components of the lighting industry develop and sell the products which make light and control it for specific seeing purposes. However, the science of lighting is very new. It has barely begun to pass from the stage of empiricism into the ever-enduring era of scientific attitude and practice. In some quarters commercialism and quackery will die hard. Medical practice was passing through that stage little more than a half-century ago. Even now only the blindly prejudiced will claim that commercialism, self-interest and quackery have been entirely eradicated. Nevertheless, long ago medical practitioners began to master and use the knowledge available. In increasing numbers, and eventually on a large scale, they dedicated themselves to serving humanity first—and best. Such practices are most profitable to the public as well as to the profession and industries involved—and eventually to its members. The reward is public faith and following.

Lighting specialists are on the threshold of opportunity for greater service to a half-seeing world, but this carries with it an equal weight of responsibility. As yet, they are the only individuals whose practice takes them everywhere in the world of countless tasks of seeing, serving light and lighting to make seeing possible—and easier. A rather formidable science of seeing provides knowledge to be mastered and used. Lighting specialists, and the various components of the lighting industry, must avoid and denounce commercialism and quackery just as medical practitioners and the medical industries have to a very great extent. If they serve the public welfare best they serve themselves and their industries best. Leaders in the medical profession made similar appeals long ago—and still do.

The world sorely needs seeing specialists and, at present, lighting specialists have a clear field and a great opportunity. By their mastery of available knowledge, by their application of it to the problems of seeing, by their conduct and attitude, their service will be measured and their progress toward professional status will be determined. Their progress in increasing human efficiency, safety, comfort, welfare and happiness, through adequate light and proper lighting, will eventually be measured by public faith and following.

THE STATUS OF LIGHTING

The neglect of lighting as a universal aid to seeing is illustrated in Fig. 4. Frankly, no claim to high accuracy is made for this diagram but at least it is conservative. It is founded upon data but its chief purpose is merely to pictorialize the status of primary factors in seeing. In the first place average eyesight is generally deficient or below normal. This is often lost sight of in the consideration of seeing tasks and seeing aids. If eyesight were universally perfect the blocks representing young, average and old eyes would reach the 100-percent horizontal line at the top of the diagram. Obviously eyeglasses can bring those averages closer to the highest level of vision and seeing. Adequate light can do much in this direction but is not a substitute for eyeglasses in correcting refractive errors of the eyes. It is a partner of eyeglasses as it is of sight.

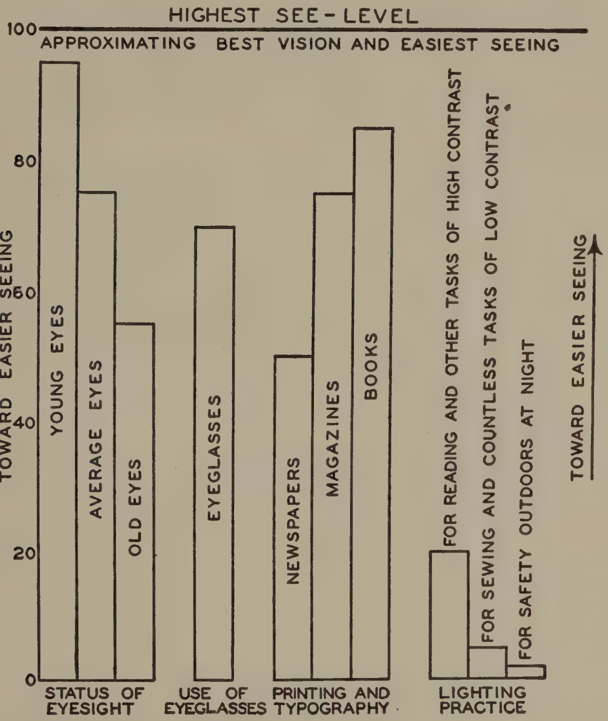


FIG. 4.—Glimpses of the lag in full usage of such aids to seeing as eyeglasses, larger type, adequate light and proper lighting.

With about one-fifth of the population in this country wearing eyeglasses and also a large number needing but not having them, the diagram attempts to illustrate the average status. Obviously eyeglasses are not utilized to their full extent toward attaining best vision and easiest seeing.

The details of many visual tasks are not controllable. However, some of them such as printed matter are controllable by someone. From the viewpoints of optimum size of type, best typography and excellent printing, great improvements toward the practical ideal have been made. Books now generally represent visual tasks which approach close to the highest "see-level." Newspapers with their smaller type and poor quality of paper and printing are far from the ideal as reading tasks.[1] Many of the other tasks of seeing are inherently more difficult than reading and in many cases they must be accepted as they are. For these and all other tasks, light can contribute much toward making seeing easier.

None of the foregoing can reach the level of best vision or easiest seeing without adequate light and proper lighting. However, lighting practice is generally far below the ideal even for such tasks as reading where the details are of high contrast due to black ink on white paper. Lighting practice is very far below the ideal for the countless tasks of low contrast, such as exemplified by black thread on dark cloth and by common tasks on every hand in the work-world.

In the many places where safety depends upon good seeing, such as on the highway at night, lighting practice and seeing conditions are of a very low order. Still, millions of automobiles rush through the blackness with only the primitive lighting of headlamps between them and eternity. Here, where quick and certain seeing are primary factors in safety, light and lighting can be utilized to great advantage in conserving life, limb and property. A civilization that can afford an average of nearly one car per family and paved highways at a cost of ten to fifty thousand dollars per mile, should illuminate the highways for safe seeing at a small fraction of the cost of the highway.

The same is true of the work-world where great strides in lighting practice can be achieved at a cost which is insignificant compared with that of the payroll or with the value of the products.[7]

It is also interesting to follow this avenue of thought into schools where young children are entering the slavery of near-vision, into homes where young and old perform a variety of visual tasks, and into all the places where critical seeing is involved. Cost should be considered in terms of benefits—and penalties.

THE COST OF LIGHT

In this changing world no greater potential contribution has been made than in the realm of light-production. Artificial light makes much of our modern world possible. Furthermore, it has become inordinately inexpensive compared with its essential nature and its beneficence. Perhaps everyone should learn to compute its cost by beginning with the cost of a unit of electrical energy. This unit is a kilowatt-hour—1000 watts connected to the lines for one hour. This means that ten 100-watt lamps burned for one hour consume a kilowatt-hour of energy.

If this unit of electricity costs ten cents it is obvious that a 100-watt lamp costs one cent to operate for an hour. But costs of electrical energy are generally much less than this, depending upon various factors and conditions. At five cents a kilowatt-hour one can operate a 100-watt lamp for a half-cent per hour. The monthly bill reveals the cost of a unit or kilowatt-hour. If it costs only three cents, one can operate a 100-watt lamp more than three hours at a cost of one cent.

Present-day sources produce light at efficiencies 100 to 500 times greater than that of the burning candle. Nature's common way of producing light from the flames of burning materials is only about one two-thousandth of the maximum efficiency which is theoretically possible. Efficiency in light-production is measured in the units of light (lumens) produced per watt. The luminous efficiency of the candle flame is about 0.1 lumen per watt. Tungsten-filament lamps commonly in use for general lighting purposes produce light at 8 to 20 lumens per watt and modern fluorescent lamps at efficiencies up to and greater than 40 lumens per watt. The luminous efficiencies of other modern lamps have passed 50 lumens per watt. The highest possible efficiency theoretically attainable for white light is slightly more than 200 lumens per watt. It is seen that light-production has progressed enormously in the present century.[8] In Chapter IV a dozen milestones are presented for the purpose of aiding the reader to view the present in proper perspective.

In 1900 artificial light cost twenty-five to thirty times more than it does now. A century ago it cost a hundred times more. In other words, one can now purchase as much light for one cent as he could a century ago for one dollar. During the same period the cost of living and the standard of living have greatly increased. Relative to progress in these directions, levels of illumination, under which prolonged critical tasks of seeing are performed, have increased at a snail's pace.

At a distance of a foot from a burning candle the level of illumination is about one footcandle. A century ago a candle or crude oil-lamp was placed near the work, and probably the illumination on the seeing task was of the order of a footcandle. Now, even with enormously more efficient light-sources and decreased cost of light, the average level of illumination on critical tasks of seeing is commonly less than ten footcandles. In the best examples of lighting practice, which as yet serve only a small percentage of the seeing done in the everyday world, the levels of illumination are 20 or 50 footcandles and in a few cases are even higher. These relatively rare cases are leading the way in the direction of easier seeing.

The cost of artificial light now competes favorably with the cost of daylight indoors.[9] In congested places this has been true for a score of years. But the daylight habit is strongly entrenched and many windows, skylights and light-courts are installed where they cannot be justified. Many admit meager light; at best most of them waste space and heat. Windowless interiors and even windowless buildings can be perfectly controlled environments with modern lighting and air-conditioning.[10] In many cases the primary accomplishment is "letting vision out" rather than "letting light in." The necessity of blackouts during World War II made many consider seriously, for the first time, the matter of daylighting. On the other hand, the development of glass bricks and other media can increase the practicability of daylighting in some cases. However, it is well to be on guard against the daylight habit which has been entrenching itself since man first came indoors.

THE SCIENCE OF LIGHTING

The science of lighting can be reduced to a chain of three links as illustrated in Fig. 5. The production and control of light are physical sciences. The former continues to expand but the latter is fundamentally complete. The lighting specialist chooses among the light-sources available. He may control the color or spectral quality of the light in special cases by means of colored filters or reflecting surfaces. He controls the light by various means, designing lighting equipment and lighting systems. However, these steps are means to an end which in general is seeing.

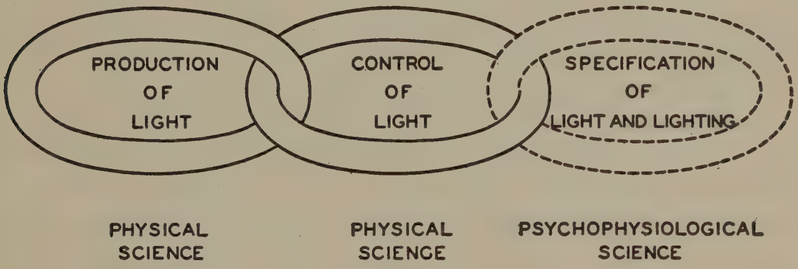


FIG. 5.—Light is just as essential as eyesight in seeing. Lighting practice involves a chain of three links. The last link—scientfic specifications of light and lighting—is the most important one. It is being forged by the science of seeing.

The third link in the chain is the most important one. This connects the lighting system and human beings. This link can be forged only by the results of researches dealing with vision, seeing, physiological and psychological effects. Specifications of levels of illumination must be based upon visibility and ease of seeing. This is also true of specifications of the kind of lighting. The basis of such specifications is a psychophysiological science—the science of seeing.

The ability to specify with confidence and accuracy is the overwhelmingly important aspect of any practice. The same fundamental knowledge is as necessary for diagnosing what is wrong as for specifying what should be done. This applies to lighting or seeing specialists as well as it does to physicians and bridge-designers.

Imagine a physician with a bag full of medicines letting a sick patient take his choice! The physician diagnoses and prescribes on the basis of medical science.

Imagine a bridge-designer with steel beams and other construction materials available. He must know the requirements of the bridge to be built. It must carry a certain load over a certain span. A well-developed physical science makes this possible if the designer has acquired that knowledge. Certainly he eliminates guesswork and is not interested in selling steel.

Without the science of seeing the lighting specialist could not prescribe light and lighting. This science is not complete nor has the lighting practitioner had a great deal of experience with its details and devices. This is why the science of lighting is very new. There has been some knowledge available pertaining to the effects of illumination upon production and spoilage in industries, upon safety and various socalled "practical" aspects. However, until recently there was no means of measuring the visibility of tasks and of specifying light and lighting on that proper basis. The science of seeing provides such means and knowledge of manifold relationships of light, vision, lighting and seeing. It includes the concept of ease of seeing and already provides a good deal of knowledge of the relationships of light and lighting with that factor. The best practices based upon the science of seeing are bound to be the best from any viewpoint. They are best for everyone.

To summarize, lighting practice was largely empirical until recently. In the absence of underlying knowledge neither the lighting specialists nor the lighting industry possessed faith and confidence commensurate with the importance of light and lighting. But the development of the science of seeing has brought about a change. Leaders in lighting practice now know that they have an extensive opportunity to serve a half-seeing world in almost every avenue of human activity. They are beginning to master the available knowledge of seeing which provides the basis for diagnosing seeing conditions and for specifying light, brightness and lighting for easier seeing.

A DIAGRAMMATIC VIEW

In Fig. 6 an attempt is made to illustrate by a diagram the place of the science of seeing not only as a foundation for lighting practice, but as the heart of it. Light-sources for the most part evolve in laboratories that are constantly at work striving to increase luminous efficiency and adaptability to the variety of increasing requirements of seeing. For the most part the lighting specialist is obliged to choose the light-source best suited for the tasks of seeing he is dealing with. The science of seeing by revealing facts establishes the truth or falsity of claims made for different illuminants. For example, it reveals special uses for sodium light where its monochromatic spectral character is advantageous.

The lighting specialist may choose among light-sources which are concentrated to the point that extreme control over the light is possible. On the other hand, he may choose extended sources when he is primarily interested in large-area lighting. With a variety of physical sizes, wattages, luminous-outputs and spectral qualities of light to choose from, the lighting specialist turns to optical control by means of reflecting surfaces, lenses, prismatic glass and other expedients. He can control the light and brightness to satisfy the requirements revealed by the science of seeing. High visibility and easy seeing are twin objectives. The science of seeing is the only source of knowledge upon which sound specifications of light and lighting can confidently be based. It provides for the seeing specialist a scientific foundation for diagnosis and specification, just as medical science serves the physician and ophthalmological science serves the prescriber of eyeglasses.

The science of seeing is exceedingly complex and, therefore, Fig. 6 can only provide glimpses; but it is an attempt to reveal how various physical, physiological and psychological aspects are

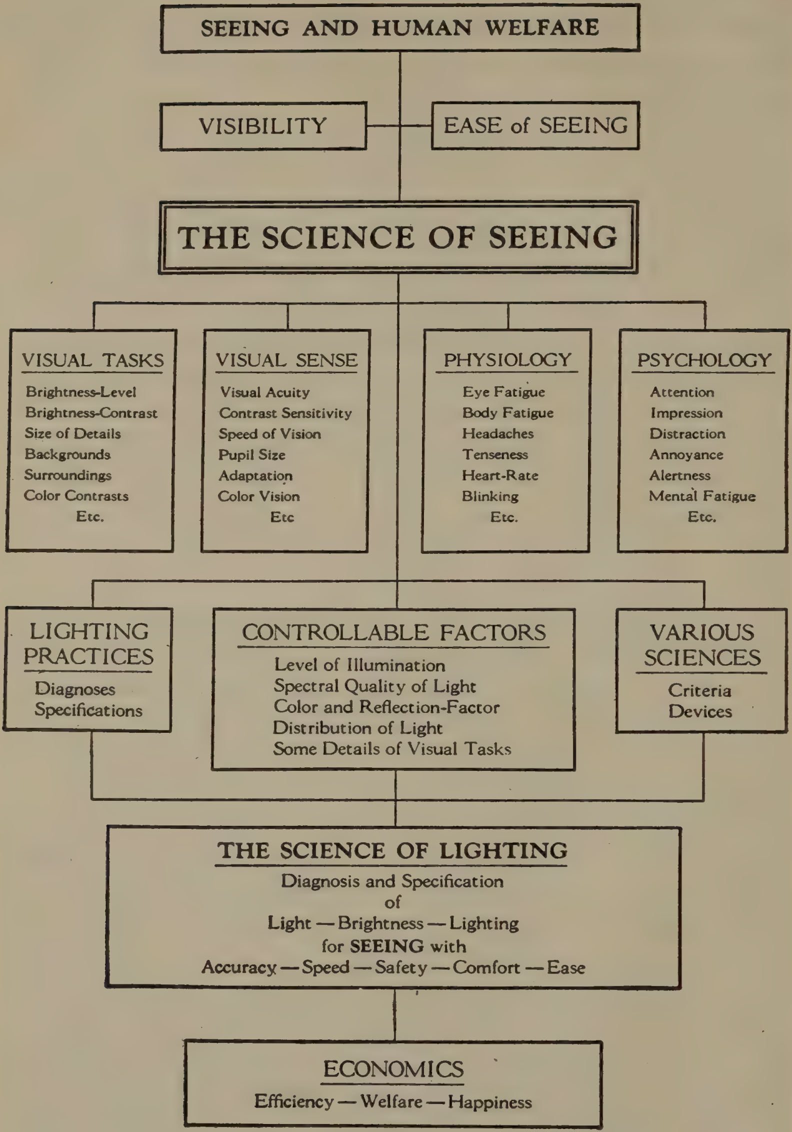


FIG. 6.—Glimpses of the ramifications and objectives of the science of seeing.

intermingled. It coordinates all three links in Fig. 5 and presents particularly a skeletal view of the third link. The science of lighting becomes a part of the science of seeing. It is a science within a more inclusive science, just as physiology is a science within the more inclusive science of biology.

CHAPTER IV

Milestones of Lighting Progress

Artificial light is literally and metaphorically the torch of civilization.[8] It exemplifies material progress and symbolizes intellectual progress. Only against the background of history can the present possibilities and goals of lighting progress be adequately appreciated. One need have little interest in history for itself, but all of us need glimpses and interpretations of it in order to view the present in proper perspective. For this reason major milestones of lighting progress are briefly presented.

MANKIND CAME INDOORS

The first milestone of progress in artificial lighting was established when mankind brought fire indoors. This was the first important declaration of independence from Nature. The building of our artificial world began. Protection, comfort and leisure even in primitive stages began to lay the foundation of civilization. Important foundation-stones, such as the family circle and leisure for thought and invention, began to be formed. From the viewpoint of lighting progress, darkness was conquered by artificial light. Perhaps no achievement of mankind outranks this in importance. But also a great illusion was born and nourished for thousands of centuries. The function of artificial light seemed to be the relatively simple and obvious one of banishing darkness. Thus artificial light became a competitor of darkness and remained so in the philosophy and practice of lighting until the present time.

THE CANDLE

From the beginning of civilization well into the era of recorded history, primitive beings must have noted that some of Nature's raw products when burned gave more light than others.

PLATE IV.—Controllable artificial light, for countless purposes, has made most of our artificial world of civilization possible and practicable. Independent of daylight or of darkness, civilized activities have been extended without limit as to time and place.

In various ways there developed the process of selection of materials to be burned for the production of light. During that long period little inventive genius was necessary in placing the selected materials in receptacles. However, the candle represents invention in high degree. Nature's materials were adapted and molded into man-made light-sources. The candle which came into existence perhaps 2000 years ago may well be taken as the second great milestone—and the first great one from an inventive viewpoint. But it still represented Nature's obvious way of producing light—by burning something—and its luminous efficiency was, and still is, about 0.1 lumen per watt. And its light is the accidental color or spectral quality determined solely by Nature and untouched by man's growing mind, increasing knowledge and developing ingenuity.

BIRTH OF MODERN SCIENCE

Increasing protection, comfort and leisure provided thinking man with increasing knowledge through observation, analysis and coordination of the obvious facts of Nature delivered to his five senses. One may trace backward a thin golden thread of knowledge into the mists of the prehistoric era. Some semblance of systematic observation in certain directions, such as astronomy, is apparent in the recorded history as early as a few thousand years ago. Even experimentation was inaugurated to some extent. However, knowledge continued to be gained largely by the more or less painful method of accidental experience or, at best, by the inefficient method of cut-and-try. Outside the realms of science these methods still predominate in our modern world—and account for some of the political, economic and social ills of mankind.

The Great Renaissance in the more advanced countries, particularly in Europe, which followed the Dark Ages or the so-called Medieval Era was fundamentally a great new declaration of independence in thought and action. It crystallized the great idea that Nature could be understood and was worth understanding. And it resulted in the great invention of modern scientific method—systematic experimental approach to knowledge. This approach extended man's attack beyond the obvious and beyond the prejudices and limitations of his unaided senses. It produces tested and testable knowledge which is the only road to incontestable knowledge.

For example, Galileo, the foremost exponent of the crystallizing scientific method of systematic experiment during the birth-pains of modern science dared to question a great illusion. The sun appears to revolve around the earth. It appeared so to every human being who preceded him and to everyone since. But the obvious was untrue and the unobvious was true. The facts established by modern scientific method denied what appeared to be true to the visual sense. Eventually, notwithstanding appearances, this great illusion has been shattered by faith in modern science.

Herein lies a lesson for users of artificial light. Many of the contributions and effects of modern lighting must be accepted on faith in modern science. This is equally true in medicine and the other practices and the practitioner must know and be guided by the truth. With the birth of modern science the way was opened for eventual great progress of knowledge in many avenues beyond the obvious. Although Modern Science got under way slowly, it soon became irresistible. The production, control and specification of artificial light have advanced tremendously by the application of modern scientific method.

THE LAMP CHIMNEY

Throughout the entire period of making artificial light by Nature's most obvious method—by burning something—the feeble flames flickered without premeditated protection. Apparently the lamp chimney of glass did not enclose the flame until about 1783. This fact alone emphasizes the incidental nature of inventiveness. The lamp chimney is the outstanding symbol of the birth of lighting equipment by adapting accessories to the light-source. The recency of this event—less than two centuries ago—is of great importance in appraising lighting practice even at the present time. However, this milestone, notwithstanding its relative recency, is only the fourth of a dozen outstanding milestones of lighting progress.

THE PIPING OF GAS

Just as the lamp chimney is symbolic of the real birth of lighting equipment, the piping of gas for lighting purposes represents the birth of lighting installations. This did not take place until about the year 1800. In fact, the beginning of the nineteenth century may well be taken as the beginning of the application of modern science for the benefit of the public as a whole. With the piping of gas, permanent lighting systems came into existence. For the first time artificial light-sources were fixed as to location at the work-places or were distributed over work-areas. Thus the way was opened for an eventual specialized lighting practice. However, the advent of the lighting specialist still had to await great progress in efficiency, controllability and convenience of artificial light.

BIRTH OF THE ELECTRICAL AGE

Today with the services of electricity so widespread that electrical energy may well be termed the life-blood of modern civilization, it is difficult to realize that only a century ago Faraday was completing his systematic experiments which revealed basic laws relating mechanical and electrical energy. Only modern scientific method could reveal the unobvious facts so deeply concealed from the unaided human senses. This new knowledge, which paved the way for endless supplies of mechanical energy to be converted into equally endless supplies of electrical energy, was to lead inevitably to the development of electric light-sources. The scientific toys of Davy—glowing filaments and brilliant arcs—were to become useful with the availability of adequate supplies of electricity. Milestones in lighting progress were now destined to follow in such relatively rapid succession that they began to overlap each other.

THE GAS MANTLE

All things when heated in the same flame do not glow with equal brilliance. With the development of hotter gas-flames, the process of selectivity extended beyond materials to be burned to materials to be heated for the purpose of emitting light. The rare-earth oxides glow brilliantly in such a flame as compared with most other materials. Thus Welsbach, in 1885, practicalized the principle of selective emission. The button of lime in Murdock's lime-light which glowed in the hot flame of his portable gas outfit as early as 1825 was thus introduced into lighting equipment and installations. It is worth noting that an invention becomes practicable not always by itself but by the timely confluence of other lines of progress in knowledge and development.

The luminous efficiency of the Welsbach gas mantle was about 1.2 lumens per watt. This is a great advance over that of the candle flame and other flames of Nature which emitted about 0.1 lumens per watt. Between these were various light-sources such as the kerosene lamp with a luminous efficiency of about 0.3 lumens per watt.

ELECTRIC LIGHT-SOURCES

With the availability of electrical energy the development of filament and arc lamps began in earnest and they began to appear in use in the decade ending with 1880. In the following four decades various arc lamps, by applying the principle of selective emission, reached efficiencies of 10 to 25 lumens per watt. But the arc lamps were eventually to disappear from general lighting purposes into highly specialized fields. Such characteristics of filament lamps as convenience, divisibility, simplicity and safety won the major lighting fields for them. At the beginning of the present century the carbon-filament lamp emitted only 3 lumens per watt. With the introduction of new filament materials and various other improvements, the luminous efficiencies of filament lamps increased. Today tungsten-filament lamps emit from 8 to 35 lumens per watt, depending upon the size and use. Thus it is seen that their luminous efficiency is 100 times and even 300 times that of the candle flame—Nature's common way of producing light. An outstanding contribution of tungsten-filament lamps is the ease with which brilliant sources can be restricted to small spaces. This made possible a great extension of control over artificial light.

BIRTH OF LIGHTING PRACTICE

Lighting practice as a distinct art and embryonic profession was born early in the present century—about 40 years ago. Without the advent of electric lighting it would probably have remained unborn. Electric filament lamps—extremely simple and completely enclosed—enormously extended the possibilities of artificial light. There were few limitations upon their location and purpose. The possibilities were great enough in extent and variety to attract and develop the specialist in lighting. Thus the lighting specialist came into existence. He could adapt the light-source and control the light. But lighting practice involves not only light-production and light-control. The specification of levels of illumination and kinds of light and lighting is the important third link in the chain beginning with the production of light and ending with efficient, safe, certain, comfortable and easy seeing.

The light-source, the lighting equipment, and the lighting installation are no more than means to an end. In this respect they are merely links in the chain beginning as far back, at least, as the power plant. The real purpose of producing, installing and paying for light is to be able to see. When the lighting specialist appeared upon the scene there was practically no knowledge available upon which he could base specifications of the proper amount of light, the proper kind (spectral quality) of light or the proper kind of lighting. He was in a position similar to that of the bridge-designer who had plenty of steel and who knew the length of the span of the bridge and the load it had to carry—but did not have the necessary knowledge of unobvious laws which would enable him to specify the amount of steel and how to put it together to carry the load safely across the span. The relations of light and lighting with vision and seeing had to be established before artificial lighting could be properly designed for adequate seeing.

For at least three decades the lighting specialist could not specify even 5 or 10 footcandles of illumination on a sound basis of either measurements or effects upon seeing. In fact, the word "seeing" rarely appeared in lighting literature. Levels of illumination increased only slightly over this period and remained, for the most part, near the level of barely seeing. If one could actually see to perform a visual task there was no knowledge available which showed that the level of illumination was not adequate for quick, accurate and easy seeing. In the work-world the influence of artificial lighting upon production, spoilage and safety was emphasized. But most tests showed that production was not greatly increased by levels of illumination greater than 10 or 20 footcandles. As a consequence levels of illumination under which most critical seeing was done averaged only a few footcandles.

Other factors such as glare received much attention. Light-sources were shaded and reflectors were turned upside down. Thus indirect and socalled semi-indirect lighting systems were developed. These were easy ways of providing general illumination for large areas. However, to one who began to analyze in terms of seeing, shortcomings of low levels of illumination and of installations of solely general lighting began to be evident. And overall it became obvious to the author that artificial light and lighting could not be soundly specified until a great many of their relationships to seeing were established for the great variety of tasks and environments with which civilized human beings were confronted. The empirical art of lighting could evolve into a science of lighting only through a science of seeing.

THE SCIENCE OF SEEING

Light and vision are essential for seeing. They may be considered as a partnership in which one is essential to the usefulness of the other. In the development of the science of vision, light was generally ignored or, at best, it was viewed incidentally. Similarly, in the development of lighting practice, vision was considered only incidentally. Therefore, much research was necessary to establish the relationships of light and sight.

In the development of this important milestone, the work of our laboratory has grown continually from roots planted nearly four decades ago. It is the only laboratory in which considerable facilities have been devoted continuously to researches in seeing for this long period over a broad front.[6] Besides having the magnificent opportunity of ascertaining how light and lighting can benefit mankind most, we have had the great advantage of a long period of continuous evolution of thought, concepts, criteria and techniques. The results of these researches and their interpretations and applications are revolutionizing lighting practice by rapidly replacing an empirical art, based largely upon guesswork and dominated to some extent by commercial considerations, with a science of lighting. Specifications of light and lighting are being placed upon a sound scientific basis provided by the science of seeing which in three decades of research has grown from crude beginnings to an extensive coordinated structure.[1] Naturally lighting practice lags far behind the dictates of science.

When the first frail tungsten-filament lamp appeared and the gas-filled lamp was in the offing, we seriously began our researches in seeing. The initial purpose was to provide a sound basis for specifying levels of illumination and kind of lighting. Soon the results began to overflow this field and now the science of seeing is providing a new, or at least an extended, basis for refining all civilized practices involving seeing. And in all these, light and lighting are essential and inescapable!

In analyzing any task of seeing, even superficially, one finds himself interested in

The visual task.
The limitations and abilities of the visual sense.
Light and lighting.

It is now obvious that an arbitrary specification of a certain level of illumination is an inadequate approach to the problem. Immediately very important questions arise. Visual tasks vary enormously in the visibility of their critical details, in the duration of the task, in the requirements of performance, etc. Inasmuch as the limitations and abilities of the visual sense in any given case are fixed, light is the only factor which is adequately controllable. The level of illumination and the distribution of the light can be varied for each task in order to make all tasks of seeing performable with approximately the same ease insofar as this is possible or practicable. Therefore, it became obvious that means should be developed for measuring visibility and ease of seeing.

Now we can look back over three decades of evolution of research and note the development of various definite approaches. They may be listed briefly as follows:

1. Adaptation to Nature's environment.
2. The relationships of light and sight.
3. The visibility of visual objects and tasks.
4. Physiological effects of seeing.
5. Quality and quantity of achievement.

Studies of Nature's levels of brightness and illumination, quality of light and distribution of light and brightness were important in themselves in revealing the conditions under which the human seeing-machine evolved in the course of a billion years or more. In themselves these studies proved nothing in regard to requirements of light and lighting. However, if we accepted the principle of adaptation so generally applied to other aspects of living things, we could scarcely avoid the conclusion that the brightness-levels outdoors might well approximate the ideal. Thus we began to suspect that the proper objective of artificial light is to compete with daylight not with darkness.

The results of many researches have established many relationships between light and sight, have provided means of measuring the visibility of visual objects and tasks and have yielded new concepts and knowledge of ease of seeing. All have contributed much to a formidable structure properly known as the science of seeing. In general the combined knowledge of seeing reveals Nature's brightness-levels to be ideal for best vision and easiest seeing. Thus the suspicion has evolved into a conclusion that the proper function and objective of artificial light is to compete with daylight not with darkness. In one sense this is a roundabout way of verifying the fact that human eyes and human beings, operating as human seeing-machines, are products of Nature and are best adapted to Nature's brightness-levels.

FLUORESCENT LAMPS

As the science of seeing was becoming a great milestone in lighting progress which reveals the real purpose of artificial light and is providing lighting practice with a sound foundation, the confluence of various lines of knowledge of light-production was bringing the fluorescent lamp to a practical stage.

Electric arcs which long had been relegated to special purposes came back totally enclosed. Developments produced high-pressure mercury arcs of promising applications. And in the other direction low-pressure mercury arcs were developing. These emit an abundance of relatively short-wave ultraviolet energy in the spectral region of $\lambda 2537$. This energy is especially active in exciting fluorescence. Thus materials which exhibit fluorescence and phosphorescence found a great place in light-production. They are frequency-changers. They absorb short-wave (high-frequency) ultraviolet energy into long-wave (lower-frequency) visible energy or light. Coating the inner walls of the glass tube containing the low-pressure mercury arc they are excited to luminescence by the ultraviolet energy. This is the fluorescent lamp in principle.[11]

The tungsten filament of high brightness confinable in a small space greatly increased the controllability of light by optical means. As a result the applications of artificial light multiplied enormously. However, for general lighting purposes, refinements in lighting required diffusing envelopes, concealment of the light-sources and the avoidance of specularly reflected images. On the other hand, fluorescent lamps are sources of relatively low brightness of the order of that of the sky or clouds in the daytime. Thus the lighting specialist and the lighting industry became much richer in light-sources by the advent of this radically different light-source. The fluorescent lamp makes it possible to use large direct components of light for general illumination and for localized light without difficulty or need for diffusion. However, they should be shaded from the eyes when they are hung low or near the user.

Control of the light from fluorescent lamps is adequate for most general and localized lighting purposes but not for many of the special purposes where tungsten lamps are serving so admirably. But in fluorescent lamps another kind of control of light became possible. Many of us for a long time have dreamed that color or spectral character of artificial light might be directly controlled in an efficient manner. Rather suddenly it became possible to mix fluorescent powders, emitting different colors or spectral qualities of light, and to coat the inner surfaces of the glass tubes of fluorescent lamps and produce daylight, white and various colored fluorescent lamps. In fact, there is no limit to these possibilities when one considers the great chemical unknown still in Nature's storehouse. By mixing these socalled phosphors in the dark under invisible ultraviolet energy one actually sees the process of controlling color and spectral character of the light resulting from the mixture of fluorescent lights.

Already a great range of sizes of fluorescent lamps is available for many purposes. Luminous efficiencies of 30 to 40 lumens per watt are common. Already by increasing the efficiency of the phosphors the luminous efficiency of the lamps has been greatly increased since the advent of the first lamp a few years ago. With all the possibilities ahead one may safely hope for much higher efficiencies. Viewing these along with high-pressure mercury arcs it may not be far to 100 lumens per watt. These lamps make it easier to produce the levels of illumination revealed by the science of seeing as ideal for maximum efficiency, safety, comfort and welfare of civilized human beings.

CHALLENGING THE SUN

The last great milestone which we are approaching from several directions may well deserve a variety of titles. The highest possible luminous efficiency at which white light can be produced is about 200 lumens per watt. Already from a crude beginning we have come one-fourth of the way. The half-way point is not actually in sight but it has clearly emerged from the stage of dreamland. Already we can produce the brightness-levels of outdoors indoors over many visual tasks. Already it is possible to provide on localized areas levels of illumination equaling the 8000 to 9000 footcandles of midsummer midday daylight. And lighting specialists and the lighting industry are now associated with the beneficence of daylight. Artificial lighting has escaped the depressing effect of competing with darkness, with all its lowly implications and associations.

But this is not the end. By following Nature's textbook we shall duplicate the good features of Nature's light and lighting. And that is not the end. We shall improve upon Nature by applying light and lighting specifically for our artificial world. Still this is not the end.

Outdoors the beneficence of sunlight is not solely in the light. The energy from the sun is the life-blood of Nature. It is more than a partner of sight. The invisible energy is just as much a part of the environment outdoors under which living things evolved as the visible energy. Already we know that ultraviolet energy kills germs and plays some part in life and health processes.[12] For a long time we have been engaged in researches upon which to base the applications of germicidal energy for the prevention of contagious diseases. For many years we have conducted researches to ascertain more about the health benefits of artificial sunlight with the goal of supplying the ultraviolet component for health along with light for seeing.

Various sources of radiant energy are ready or in the offing waiting to serve mankind in this and other ways, when and if we learn how they can serve. Never have we been so rich in sources of light and radiant energy. Fortunately the science of seeing evolved in time to reveal adequate goals for any light-sources available or yet to be born. However, an enormous amount of research must be done before we have complete knowledge of the benefits of radiant energy which can even now be supplied by available sources. In the meantime our faith in sunlight as the life-blood of creation molds our thinking, buoys our hopes and energizes researches in this direction.[8]

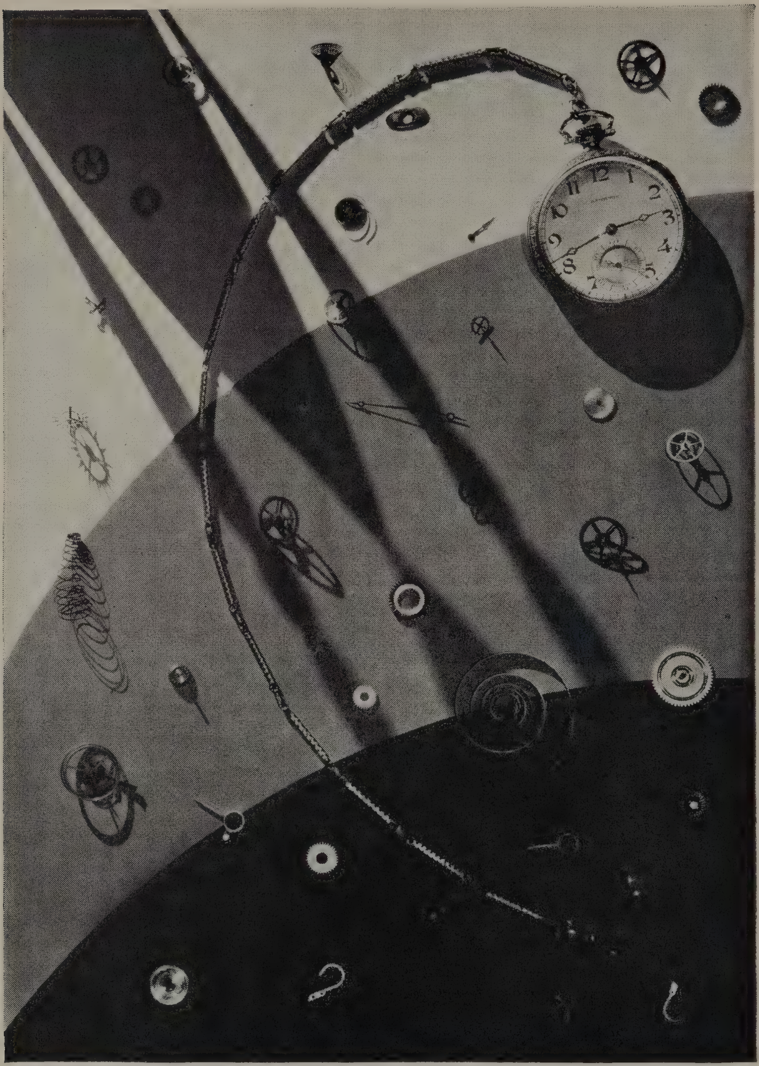


Plate V.—The visibility of an object or task is largely determined by four primary factors. These are (1) the brightness of the background against which the object is seen; (2) the size of the critical details; (3) the brightness-contrast between the object and its background; and (4) the time available or necessary for seeing. Color is generally a secondary factor.

CHAPTER V

What Makes Things Visible

Suppose we are looking at a summer landscape. First we are conscious of brightnesses and colors. These are all that we actually see. From them arise all the details which closer scrutiny reveals. They give distinction to any object. They are responsible for form, by which we generally recognize objects.

The landscape may be canopied by a blue sky whose bluish light illuminates the sharp shadows by which the direct light of the sun models objects and gives depth to the scene. On an overcast day the sharpness of the shadows disappears and the entire landscape loses depth. Objects lose much of their distinction and the entire scene is flattened and loses much of its liveliness.[13] It is well to bear this in mind when appraising indirect lighting from large areas.

Nature is a vast textbook with countless pages. Outdoors we may witness continuous changes in the appearance of the entire landscape and of its details. There, changes occur with the changing position of the sun, and also with the shifting clouds, which alter the lighting from predominantly "direct lighting" on a clear day to completely "indirect lighting" on an overcast day. With such a textbook of endless demonstrations of lighting effects, which so obviously are good, bad or indifferent, it is surprising that many lighting practices of the past have so completely ignored them. In the stage of empirical lighting practice, which is coming to an end with the beginning of a scientific era, many practices were inaugurated and continued upon a basis of expediency, engineering aspects and even commercialism. Certainly there is adequate evidence that the influences of lighting upon what one sees and feels were not given proper weight amid the dominance of engineering and commercial considerations.

SWIFT SILENT MESSENGER

Brightness and color are not inherent in the objects, in the light, in the visual sense, or in the realm of sensation and mind. Brightness and color are the combined results of all these elements in the chain from the object through the visual sense to the mental terminal. What we carelessly term, light, is the messenger.

Let us return in our imagination to that period, eons ago, when living things were simple organisms. Somehow through the process of slow evolution, which is a convenient means of detouring a mighty mystery, the simple organisms gradually became more and more complex. Eventually different senses evolved—touch, taste, smell, hearing and sight. In that order the senses conquered distance. We touch something by extending our arms. Touch and taste require contact. We smell things at some distance, but still there is contact with vaporous material exuded by the object. We hear sounds originating at still greater distances, but there still must be contact through a material medium, such as air or metal. Sound does not pass through a vacuum. However, the sense of sight really conquered distance in a large way. We can see stars at incomprehensible distances—if they emit enough light.

During the evolution of living things and their senses, sunlight flooded the earth. This invisible radiant energy upon which the very life of living things depended became utilized during the evolution of the visual sense. By this means it became possible to see things at a distance. The eyes became "radio receiving sets" attuned to radiant energy from the sun, of such wavelengths as are most abundant in sunlight.

Such details, countless in number, coordinate into a mighty structure of evidence which powerfully supports the principle of adaptation to environment. One cannot intimately study the many aspects without concluding that human eyesight and human beings, operating as seeing-machines, are best adapted in general to natural light and lighting and to the brightness-levels outdoors in the daytime. Of course, this is not proof, but it provided adequate encouragement for a research attack which would reveal the truth. In later chapters, much evidence reveals that visibility and ease of seeing are generally most satisfactory at brightness-levels approximating the average outdoors in the daytime.

As we look at a landscape outdoors in the daytime, we see it flooded with abundant light. We are no more conscious of the stream of invisible energy flowing from that scene to our eyes than we are of other invisible or unobvious effects. We are not conscious that sunlight exerts pressure upon a surface; nearly 100,000 tons on the entire surface of the earth at midday. We are not conscious that light travels with the enormous speed of 186,000 miles per second. We are not even conscious that this universal messenger, which serves us through our visual sense, is invisible.

Such facts, important in themselves, should also prepare us to accept many other facts of light, vision and seeing which are equally unobvious. This same kind of invisible radiant energy, which has revealed to modern science so much knowledge of the invisible constituents of atoms and stars, is of service in an infinite variety of ways in making objects adequately visible to us and our tasks of seeing appropriately easy in a civilization bent on reducing or banishing burdens.

EYES AS OPTICAL DEVICES

From any scene or task, such as this page of printed matter, a stream of invisible energy flows toward the eyes. The black letters of very low reflection-factor give configuration to the cross-section of that stream. The optical system of the normal eye converges and reduces the cross-section of that stream of energy, and focuses a fairly accurate image of this page—or any other scene—upon the retina.

There is little we can do about the eye or visual sense but we can aid it by various means. Therefore, an understanding of its complexities is generally of academic interest excepting to specialists. Nevertheless, it is well to know something of its major parts as shown in a vertical cross-section in Fig. 7.

If the eyeball is too short or too long, or if the lens has lost much of its resilience so that it cannot be adequately altered in shape by the ciliary body or muscle, the image of this page will not be focused upon the retina. As a result the words will appear blurred. This will also result from other imperfections of the eye. In such cases, eyeglasses are prescribed to "correct" the optical defects. Actually, eyeglasses do not correct but counteract the defects more or less completely.

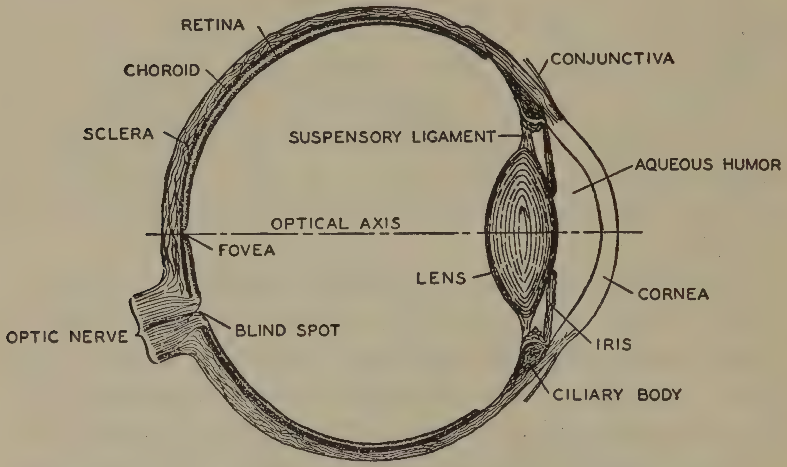


FIG. 7.—A diagram of the central vertical section of the human eye.

Each eye is turned in various directions by six (extrinsic) muscles. Inasmuch as we have two eyes, they must operate as a team if we are to have satisfactory binocular vision with all the advantage of the perception of depth or of stereoscopic vision. The muscles of convergence accomplish this, directing the line of sight of each eye so that both converge upon the object while the lens of each eye is properly "accommodated" so that the image in each case is focused accurately and in its proper place upon the retina.

The retina covers the inside of the rear portion of the eyeball. Physically it consists of many millions of elements of the optic nerve spread out into a thin layer of receptors or sensitive elements. Each of these may be considered to be analogous to a telephone which makes the retina a telephone exchange of enormous magnitude. But these receptors are of finite size so that the retina is commonly described as a mosaic.

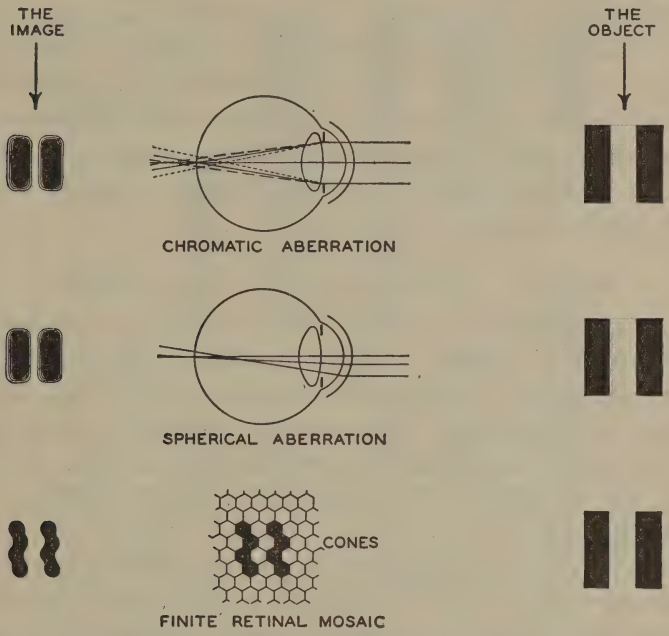


FIG. 8.—Illustrating three limitations of eyesight in seeing very small details. For the purpose of illustration, the object and its image are greatly magnified.

Even though the image of an object is accurately focused on the retina, it is distorted by this "mosaic" as illustrated in Fig. 8. The optical system of the eye, being equivalent to a simple lens, has two inherent major optical defects, also illustrated in Fig. 8. One is commonly termed spherical aberration which results in a distortion of an object. For example, the retinal image of a checkerboard, instead of being an accurate geometrical figure with straight and parallel lines, is distorted into lines more or less curved. In addition to this, there is another defect. A simple lens cannot bring to a focus at the same point radiant energy of different wavelengths. Therefore, the edges of the image are more or less fringed with a colored band when the object is illuminated with illuminants of extended spectral character which contain all the colors of the rainbow. This is known as chromatic aberration.

Although we are endowed at birth with these various facilities, we have to learn to use them. We also learn to ignore such defective results as those of spherical aberration. In addition we learn to interpret many complex muscular stresses and eye-movements. Even then we are often misled by countless optical illusions for we never perceive a perfect counterpart of the physical reality which exists out in space.

FOUR FUNDAMENTAL FACTORS

As we scrutinize an object, a visual task or a scene, we find many factors in complex combinations which make details visible and recognizable. Brightness is involved in some way with all factors and combinations. In general, brightness is overwhelmingly important but color, too, is widespread and adds complications. For the purpose of fundamental analyses, color is omitted for the present.

If one examines this page of printed matter carefully, the details are visible, and the words are readable, by virtue of four factors. They are (1) size of the letters and of their distinguishing details; (2) the contrast in brightness between the "black" letters and their "white" background; (3) the actual brightness-level of the page as a whole and particularly of the background; and (4) the time available for seeing. If this printed matter is to be readable, each of these four factors must have values above a certain minimum or what is termed, threshold value. This is illustrated by the diagram in Fig. 9.

If the size of type on this page were in the neighborhood of 3-point, the printed matter would be barely readable by persons with normal vision under ordinary lighting conditions. The size of type in type-design is a complex matter, but for our purpose it may be considered to refer to the overall vertical dimension from the top of the longest "ascender" to the bottom of the longest "descender." A "point" is approximately one seventy-second of an inch. Books are commonly printed with 10-, 11-, and even 12-point types. For school-children even much larger type-sizes are used. These are "factors of safety" which have been demanded by readers who would never be content to read type-sizes that are *barely* readable. They are also a concession to deficient vision and prevalent poor seeing conditions.

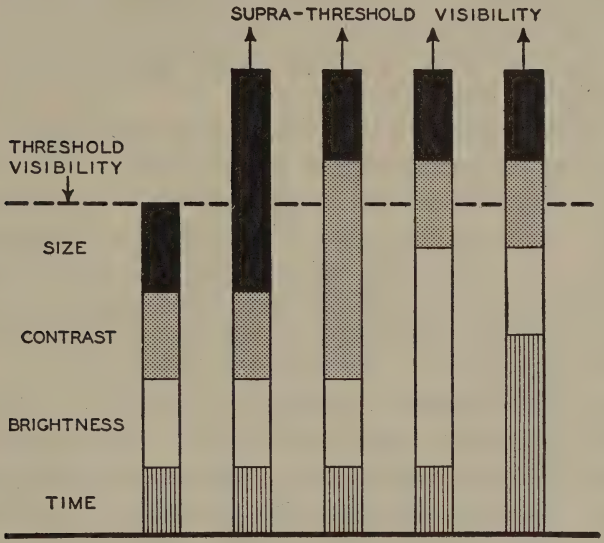


FIG. 9.—Illustrating the interdependence of the four fundamental factors which determine the visibility of objects. Contrast always involves brightness and sometimes color. However, color as such is generally among the secondary factors and is treated separately.

We are conscious of the factor of size and make certain demands to which publishers accede to an extent which appears to them practicable. However, in countless other tasks size of details is not so readily controllable and generally is not at all controllable. We must accept these tasks, but not necessarily without other aids such as light and lighting. If the size is too small to be visible to the "naked" eye, a magnifying glass, a microscope, or a telescope is used. But when it is possible to distinguish fine details, other aids such as appropriate backgrounds in some cases, and more light and better lighting in all cases, are not generally demanded or utilized. Instead the work may be held closer to the eyes, which in effect increases the visual size. Countless visual tasks are performed for long periods near the "see-level" of barely seeing instead of raising this level toward easier seeing by various means that are always available.

Brightness-contrast is a factor commonly overlooked and neglected. The brightness-contrast of the "black" printed letters and words against the white background of this page is high. It is almost the maximum possible. The test-chart of the eyesight specialist consists of letters, for example, printed with black ink on white cardboard. This has contributed somewhat to overlooking the variety of brightness-contrasts in the visual tasks other than reading matter.

Brightness-contrast is exceedingly important. It is very low for a black thread on dark cloth. Also it may be just as low for a white thread on white cloth. This factor, generally ignored by eyesight specialists and inadequately considered in the science of vision, properly assumes its great importance in the science of seeing. The minimum size of an object which is barely visible is many times greater when the brightness-contrast is low than when it is high. For example, a 12-point type printed with black ink on a dark gray background may be only as barely readable by normal eyes as a 3-point type is when printed with black ink on white paper. (See Visibility Indicator on inside of back cover.)

The brightness of an object or of its background is the primary factor upon which visibility depends. An object in the shade is not as bright as it is in the sunlight. Obviously the brightness of an object, such as this page, depends upon the amount of light upon it; that is, upon the level of illumination measured in footcandles. Therefore, brightness is the most generally controllable factor in seeing for it depends upon light and lighting. However, brightness also depends upon something else.

Look at the pattern of a rug or other floor-covering. It varies greatly in brightness even though the illumination of its surface is uniform. The same is true of a white cuff projecting from the dark sleeve of a coat. Thus it is seen that brightness is the combined result of the level of illumination upon the object or surface and of certain reflecting characteristics of the surface of the object. This fact is of great importance in seeing, and particularly in lighting for seeing, but it is too often overlooked.

It takes time to see. This may be demonstrated in many ways. In fact, if one knows what to look for he can observe many variations of the time factor on every hand. The spokes of a wheel are no longer distinct if it revolves at sufficient speed. Actually a spoke is moving too fast to be seen distinctly. The lag is in us, not in the speed of the light from the object. For objects at astronomical distances allowance must be made for the finite speed of light, but none is necessary in seeing nearby objects. The lag in us is due to physiological processes in the retina, to various "connections" and finally to mental alertness and so-called reaction-times. In general, it takes one- or two-tenths of a second to recognize an object under fair seeing conditions.

Look at the front page of a newspaper through the shutter of a camera. As the exposure is decreased sufficiently, only the larger letters will be readable. Careful investigations reveal that it takes twice as long to see with 100-percent certainty as to barely see an object only half the times it is presented. It requires ten times the brightness in the former as in the latter case. Many work-world tasks of seeing are more or less analogous to driving rapidly past a scene. Only the objects of high visibility, or those most striking for any reason, are visible at the higher speeds.

The foregoing are mere glimpses of the notable four primary factors upon which high visibility and easy seeing depend. One or more factors can compensate for a deficiency in any other factor but each must be above a minimum or threshold value as indicated in Fig. 9. However, the magnitude of any or all of three factors determines the threshold value of the fourth factor. For example, if this type were so small that it could just barely be read under the present conditions of brightness and brightness-contrast, the minimum size that could be read would be still larger if the amount of light falling on this page were reduced or if the contrast were diminished by dyeing the paper gray. Countless tasks of seeing involve these factors in an infinite variety of combinations. The controllability of the various factors also varies. One or more may be fixed beyond control, but generally brightness, through light and lighting and often by means of backgrounds of proper reflection-factors, is controllable.

HIGHLIGHTS AND SHADOWS

Any scene is a complex combination of highlights and shadows. These model three-dimensional objects, giving them form, which generally makes it possible not only to see them but to recognize them. A pin lying on a carpet may be invisible until one catches the glint of its highlight, an imperfect image of a bright area or light-source. The modulation of light and shade over the curved surface of a sphere gives it recognizable form.[13] On every hand are examples of the value of highlights and shadows in seeing. The seeing specialist can turn these to advantage by directing the light properly from a light-source of suitable area and brightness.

It is easy to demonstrate that, in extreme cases, some properly directed light increases the visibility of an object more than hundreds of footcandles of diffused illumination. On the other hand, it requires ingenuity to get rid of objectionable highlights or shadows which reduce visibility and cause annoyance, strain and fatigue in many tasks of seeing involving glossy or polished metal surfaces. Generally a combination of adequate diffused general illumination and supplementary directed light solves the countless problems of this character.

Measurements of visibility provide the only reliable means of determining the effect of directed light in properly revealing or modeling objects. No one is capable of estimating accurately by mere inspection with the unaided eye. One may be able to distinguish between extreme conditions that are obviously good or bad. However, one may well beware of the seeing specialist who does not make measurements of visibility. We would have little confidence in a physician who guessed at blood pressure.

The subject of highlights and shadows is so complex that it is difficult to discuss in detail. The reader should get far more out of a few simple observations and experiments than from pages of discussion.

BACKGROUNDS

Drop a small object on a carpet which has a small pattern. The object is likely to be difficult to see. The pattern in effect conceals the object. This is the underlying principle of protective pattern and coloration in Nature. A brilliantly colored and conspicuously patterned bird commonly fades into a natural setting. Even the higher reflection-factor of the underside of animals tends to reduce the shadow on this portion. The result contributes to inconspicuousness.

With these principles in mind, one may well be surprised at the notable lack of appreciation of the value of backgrounds. Unwittingly the art of camouflage is practiced far too commonly where critical seeing is done. The work-bench may be strewn with objects. Instead, a plain background, devoid of pattern, and of correct brightness, can readily be provided in many places. The wise watchmaker commonly spreads the minute parts of a dissembled watch on a plain white paper which he replaces from time to time.

A background may be white or black, gray or colored, depending upon how the objects silhouetted against it are rendered most visible. Even casual observation will often reveal whether the background should be white or black. If the former is true, the brightness of the background may be further increased by illuminating it with additional localized light. If a black background is indicated, the objects to be seen might be additionally illuminated by localized light screened properly from the eyes. Black velvet provides a darker background than black paint. An almost perfectly black background may be produced by lining a box with black velvet. A hole in this box will be as much darker than a surface of black paint as the latter is darker than a surface of white paint under the same amount of light.

In the consideration of backgrounds for better seeing, the question of localized light is commonly involved. Regardless of the general illumination, which is always essential for safe and comfortable seeing, a localized light-source can do much toward increasing visibility and making seeing easier. One need only to watch a skilled worker dealing with fine parts at a bench to see the value of a localized lighting unit. One may readily demonstrate to his own satisfaction the value of a shaded local light-source placed in various positions to ascertain the advantages.

The light-source should finally be fixed in position if the work can be oriented properly in relation to it. Try reading a steel scale or threading a needle with suitable localized light and background. Sometimes the localized source should be a brilliant filament of a lamp, but usually the images reflected from metal surfaces are too bright. The specularly reflected images from polished surfaces are commonly subdued to reasonable values by a source of lower brightness—a diffusing glass or a fluorescent lamp. Even casual observations with almost any object and lighting condition will reveal the great importance of backgrounds and of directed supplementary light in addition to general illumination. Lighting for seeing consists of much more than adequate footcandles over the entire area of work.

COLOR-VISION IS GOOD MEASURE

In specific cases color can be utilized to good advantage to distinguish objects and to make surroundings more pleasant. Even spectral character of light assumes much importance in many cases. The color of an object depends upon the light as well as upon the selective reflection (or transmission) of light by the object.

We are able to distinguish about 150 different hues, including those of the spectrum or rainbow and the family of purples which do not exist in the spectrum. Each of these hues may be diluted with white to make tints or with black to make shades.

Therefore, about 20,000 different colors can be distinguished. However, in a broad sense, a given color can be altered in brightness by the amount of light it receives. Thus each color can in effect become a series of shades by varying the amount of light from very low levels to very high ones such as those outdoors in the daytime. On this broad basis, the number of distinctly different colors mounts into millions.

Color discrimination is particularly important in dyeing where great skill is necessary and in railroading and navigation where colored signals have been specially developed. However, it is also important in everyday purchasing in department stores, dealings with decorators and wherever one wishes to match or to choose a color carefully. In such cases, one must decide upon the illuminant that is predominantly important. Is one to be interested in the daytime or nighttime appearance, or both?

Color-vision is secondary in importance to brightness-vision. However, it does spread a magical drapery over everything. We are not generally conscious of color but we would be if color-vision suddenly failed us. Then the world would be one of grays, with white and black at the extremes. That would be a drab monotonous world. By comparison our world of color really becomes important. Color does add something to the visibility of objects in general and in special cases where the brightness of two colors is the same, only color remains to make them distinguishable from each other. With all these aspects in mind it should be obvious that color has its place in making seeing safer and easier—and more interesting as well.

SEEING IS DECEIVING

In order to caution the reader against the many deceptive illusions the familiar epigram—seeing is believing—must be challenged. Actually it is impossible to see things exactly as they are related to each other. There are many sources and kinds of illusions.[14] Only a part of what we perceive comes through the senses from the objects we are looking at. The remainder comes from within. Some of the illusions are due, in part at least, to shortcomings of the visual sense. However, we are also misled by our past experiences, associations and other more or less obscure influences which create illusions. For example, the hat illustrated in Fig. 10 appears much taller than the brim is wide. Actually the two dimensions are equal. The explanation of this illusion is so involved in conjecture that it is best to accept the fact. In Fig. 11 the two parallel horizontal lines in each case are parallel notwithstanding appearances.

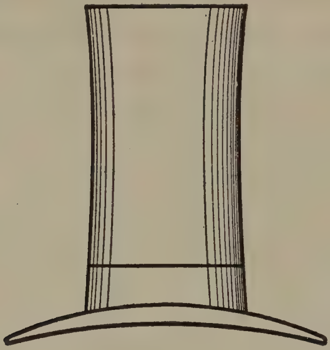


FIG. 10.—Seeing is deceiving. The width of the brim equals the height of the hat.

That we cannot ever see the actual reality or relationships of lines, forms, brightnesses and colors is due in part to the fact that each is affected by its environment and one can never completely get rid of environment or surroundings. A simple bright area appears brighter than it is when it is viewed amid a surrounding dark field. Conversely, it appears darker than it is when the surrounding field is brighter than it is. This is illustrated in Fig. 12.

If we work in a dark room under a red light, the light soon ceases to appear as red as it actually is. On the other hand a red area appears redder than it actually is when it is surrounded by green. Conversely the red area appears to be dulled in color when it is surrounded by a more intense red. These experiments are readily performed with colored papers. Moderate tints are preferable.

A bright area appears larger than it actually is when surrounded by a darker area. Black stockings make legs appear trimmer than white ones. The powerful influence of style is demonstrated by the lowly place of black stockings notwithstanding their fundamental advantages in many cases.

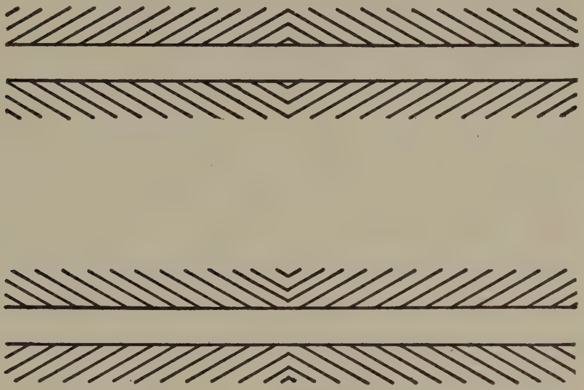


FIG. 11.—The horizontal lines are straight and parallel. Everywhere we are confronted by illusions. Often they account for claims or conclusions which are unsound.

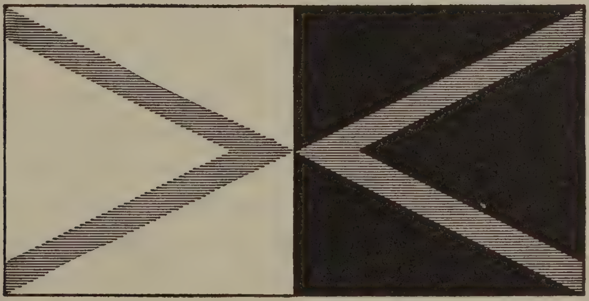


FIG. 12.—The V on the left is of the same brightness as that on the right. There is no substitute for measurements. Our unaided eyes have gross limitations—and are easily misled.

A level of illumination of 100 footcandles obtained from fluorescent daylight lamps may appear to be only 50 footcandles. This light, simulating and blending with daylight, arouses an association of natural daylight. Where daylight is abundant indoors we have learned to ignore its abundance and actually appraise the level of illumination lower than it is. We transfer this tendency in underestimating the level of illumination provided by the artificial daylight from fluorescent lamps.

If we whiten the light of an automobile headlamp by using a blue-green bulb which reduces the light-output one-third, we overestimate the amount of light. We associate the whiteness of the light with well-charged batteries, new lamps and clean reflectors which usually result in more light from headlamps. We are deceived—for a time—into believing that we have even more of the whiter light than in the case of the ordinary clear bulb which supplied a yellowish light. But such illusions wear out as we gain experience in driving with the whiter light of actually lower intensity.

These and many other illusions must be recognized if we are not to be deceived. In a long experience the author has accounted for many misconceptions and false conclusions arising from illusions. It is a very complex aspect of seeing, but if one is forewarned he is forearmed to some extent.

There are many illusions that cannot be overcome because they are, in a sense, realities even though they give an appearance to an object which it does not have. In such cases no amount of experience can overcome the false deliverance of our senses. For example, the bright hot filament of a lamp appears many times larger than the filament actually is. This is the phenomenon of irradiation and is inherent in our visual sense. Similarly the phenomenon of induction, which makes a bright area amid darker surroundings appear brighter than it actually is, is inherent in our inner realm of sensation. The same is true of the phenomenon of simultaneous contrast which makes one color such as green enhance another color such as red or purple.

All these and many other factors and conditions, which make seeing deceiving, can be demonstrated with much interest and some profit. They also afford another view of the complexities of seeing. Many illusions can be turned to advantage in lighting, seeing, decoration and camouflage and the seeing specialist should be on guard against their influence in diagnosing seeing conditions.

CHAPTER VI

Brightness Is Omnipotent

The primary purpose of light is to produce brightness. In fact, this is its overwhelmingly important contribution to seeing. Notwithstanding this simplicity of purpose, neither brightness nor the production of brightness is adequately appreciated in considerations of lighting, visual tasks, and responsibilities of seeing. Obviously if light did not produce brightness, objects would remain invisible and our visual sense would be useless. We would have to "see" with our other senses as blind persons do. Notwithstanding the omnipresence of brightness it is not generally measured. Without measurements, understanding progresses slowly and cannot possibly be accurate or adequate. Lighting for seeing might well be viewed as brightness engineering but lighting practice of the past has been far from that.

BRIGHTNESS ENGINEERING

Footcandles have received relatively too much attention and brightness far too little, considering their relative importance in lighting for seeing. One reason is that footcandles are easy to measure but the measurement of brightness requires a more complex device[15] and generally much more effort. Another reason is that it is easy to make a sweeping recommendation of footcandles on the work-plane or work-area. Consideration of brightness involves details and a far more intimate knowledge of seeing and of factors which influence seeing.

This page of printed matter is illuminated more or less uniformly by perhaps a few footcandles of artificial light or by 100 footcandles or more if it is being read in the daytime near a window or on a porch. In both cases, the printed matter is readable by persons with normal eyesight because there is a large factor

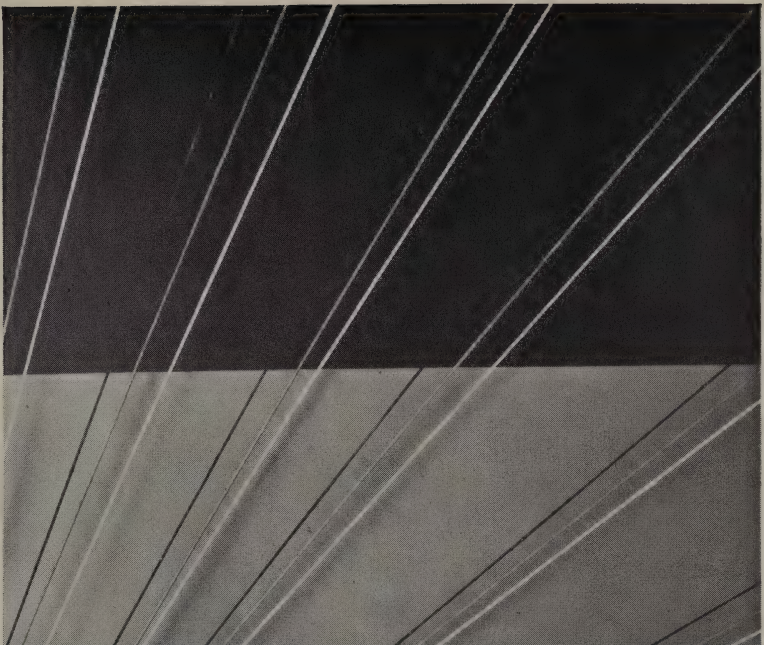


Plate VI.—White, gray and black threads viewed against three backgrounds of different reflection-factors. Thus, under the same level of illumination, the visibility of each thread depends upon the brightness of the background and the brightness-contrast between the thread and its background.

of safety in the type-size. But in the two cases the readability differs; that is, the printed matter is not readable with the same degree of ease. This is a subtle unobvious factor that can only be determined by tedious researches which invade the inner realm of the reader and deal with physiological effects of seeing.

If one is reading near a window or on a porch toward the end of the day when daylight is waning the brightness of the page is decreasing. Eventually it decreases to the point where it is obviously difficult to read. Later one can barely read. Before this point is reached the reader may hold the page closer to the eyes thereby increasing, in effect, the size of the type. Finally the brightness decreases to the point where one can no longer read.

The brightness necessary for barely reading is readily determined for a fixed distance and a given reader. The brightness of this page is obviously too great for comfort when illuminated by full sunlight at noon. Between these two extremes is a large range of brightnesses for which readability or ease of reading varies greatly. It is the function of the science of seeing to determine the relation of brightness to visibility and to ease of seeing. Incidentally, it has been shown that the brightness-levels for easiest seeing are of the order of those outdoors. These are commonly many times greater than the brightnesses of most critical tasks of seeing performed indoors. The available proof of this is presented in later chapters.

The importance of brightness is not confined to the visual task—objects, critical details and their backgrounds. Seeing conditions involve brightness of the immediate surroundings of the visual task and also brightnesses in the entire visual field. Relatively high levels of illumination—hundreds and even thousands of footcandles—are necessary to make some visual tasks comparable in visibility and ease of seeing to other tasks which are illuminated to only 10, 20 or 50 footcandles. In the case of distinguishing minor differences in color of "very dark colors" it is readily demonstrated that 1000 footcandles and more are not only desirable but are necessary for accurate color-discrimination. Even the "lighter colors" should be viewed under levels of illumination of 100 footcandles or more.

In addition to the task itself, good seeing conditions involve the brightness of the immediate surroundings and of the entire visual field, for we cannot see with ease and comfort, for long periods, amid the dark surroundings due to stained walls and purely direct lighting. The annoyance of glaring light-sources is due not only to their inherent high brightnesses but also to their extreme contrast in brightness with their surroundings. Brackets containing bright lamps are more glaring against a dark stained wood panel than against a lighter background. The powerful headlamps of an automobile are incomparably more glaring at night amid dark surroundings than in the daytime.

Everywhere, in an infinite variety of ways, brightness influences visibility and seeing. Indeed, brightness engineering must be a basic and extensive part of the practice of the lighting specialist, or even of the seeing specialist, if his efforts are to be properly directed toward easier seeing. Adequate proof of this statement is presented in this and later chapters.

BRIGHTNESS AND DIFFUSE REFLECTION-FACTOR (DRF)

Excepting for self-luminous objects and the highlights reflected by shiny surfaces, brightness is due to light diffusely reflected from surfaces. Colors are also born in this manner. Freshly fallen snow scatters the incident light in all directions very efficiently. A pile of dry powdered lamp-black also scatters the incident light in all directions, but very inefficiently. Both are diffusely reflecting materials.

The same is true of dry colored pigments. In such cases the light suffers internal reflections in the minute valleys of the diffusing surface and emerges in all possible directions. In the case of dry colored pigments this results in the reflected light being colored by selective reflection. The effect of this selectivity can be demonstrated by poking a finger in a pile of flour or white pigment. If the powder reflects some wavelengths of light more than others, the hole will not appear colorless. By multiple reflections of light within the hole, the imperceptible or barely perceptible color of the socalled white powder will be augmented to the point that it may be quite conspicuous.

When dry powdered pigments are mixed with oil and spread on a surface, the paint dries with more or less gloss. This results in highlights which are more or less imperfect images of bright sources or areas. However, beneath this thin shiny surface, diffuse reflection takes place. For the present we shall ignore the glossy or polished surface and deal with the more important matter of diffuse reflection.

The footcandle is our unit for measuring the intensity of illumination which is expressed more pictorially as level of illumination. Assuming that the illumination of this page is uniform, the letters are illuminated to the same level of footcandles as the "white" paper background. Still the "white" background is obviously much brighter than the "black" letters. Actually the letters appear black but they do possess brightness, for they reflect about three percent of the incident light. The paper diffusely reflects about eighty percent of the incident light. The diffuse reflection-factor of the paper is 0.8 or 80 percent and of the ink is 0.03 or 3 percent. In both cases there is very little gloss and the brightnesses are due to their diffuse reflection of light. Glossy surfaces are discussed in Chapter XIV dealing with specular reflection.

The paper of this printed page is about twenty-five times brighter than the ink for the simple reason that it reflects twenty-five times the amount of light reflected by the inked letters. Obviously footcandles are meaningless in expressing brightness. They have nothing to do with brightness excepting through the diffuse reflection-factor of a surface. They have nothing at all to do with the brightness of a polished surface due to specular or "mirror" reflection.

Lay a silvered glass mirror on this page. It has little brightness of its own. Still, it is receiving the same footcandles as the page of printed matter is, but the white paper has brightness of its own by virtue of its diffuse reflection of light. The brightnesses seen in the mirror are images of other bright surfaces such as a light-source or surfaces such as the ceiling which diffusely reflect the incident light.

Thus it is seen that the diffuse reflection of light by a surface apparently gives brightness to the surface. The diffuse reflection-factor of the surface is expressed in percent of that of a theoretical surface which diffusely reflects all the light incident upon it. In fact, the diffuse reflection-factor of a surface is the percentage of the total incident light which is diffusely reflected by the surface.

As one looks around at objects it is obvious that polished, glossy or shiny surfaces also reflect highlights which are generally imperfect or distorted images of other bright objects such as light-sources. This kind of reflection is termed, specular reflection. Unless otherwise stated, diffuse reflection is generally meant in discussions of brightness and reflection-factors.

THE FOOTLAMBERT (FL)

If a fly-leaf of this book is laid flat and viewed from different directions it will appear of approximately the same brightness from all directions. This is the primary characteristic of a surface which perfectly diffuses the light. This condition is closely approached by a white blotting paper and even more so by a dry white powder. For example, if a flat dish is filled with a dry white powder and then the top surface is gently leveled off, it will represent, for practical purposes, a perfectly diffusing surface. If it reflects all the incident light, which the most refined white pigment does not quite do, it would be a perfectly diffusing and perfectly reflecting surface with a diffuse reflection-factor of 100 percent. Such a surface, illuminated by one footcandle, would have a brightness of one footlambert.

Every unit in use is arbitrary whether it be the pound, foot, volt, watt or any other. One need not know its origin or definition in order to use it. He needs only to be acquainted with its magnitude. The unit of brightness in common use is the footlambert. It is the brightness of a perfectly diffusing and reflecting surface illuminated by one footcandle.

A surface may be perfectly diffusing without reflecting all the incident light, for example, a dark gray dry powder. If a diffusely reflecting gray powder, or gray blotting paper reflects only ten percent of the incident light, a footcandle of illumination produces a brightness of only one-tenth footlambert. Therefore, the brightness in footlamberts of a diffusely reflecting surface is found by multiplying the footcandles by the diffuse reflection-factor. In other words, the brightness of a diffusely reflecting surface, expressed in footlamberts, is the product of the diffuse reflection-factor and the footcandles of illumination. Thus,

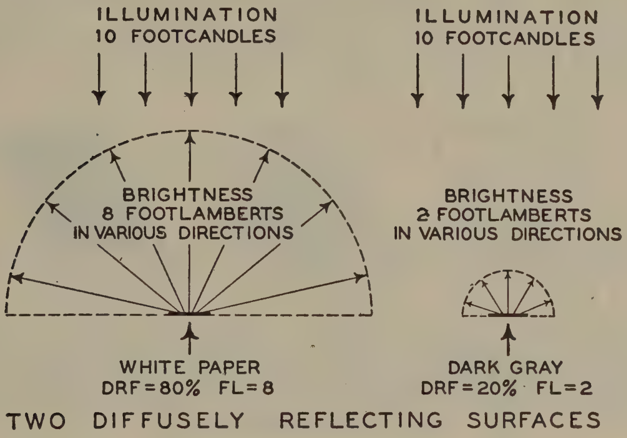


FIG. 13.—Brightness is almost all-important in seeing. We see brightness, not illumination. In these two cases the surfaces are illuminated to a level of 10 footcandles. However, the right-hand surface reflects only one-fourth as much light as the left-hand surface—and is only one-fourth as bright.

$$\mathrm{DRF} \times \mathrm{FC} = \mathrm{FL}$$

In Fig. 13, two examples are graphically presented. Both of the perfectly diffusing surfaces are illuminated to a level of 10 footcandles. One surface reflects 80 percent of the light, the other 20 percent. The former is four times as bright as the latter when viewed from any direction. The brightnesses are 8 and 2 footlamberts, respectively, when illuminated to a level of 10 footcandles and 80 and 20 footlamberts when the level of illumination is 100 footcandles.

FOOTCANDLES AND FOOTLAMBERTS

Now let us turn to some common cases in order to illustrate a shortcoming of footcandle measurements and specifications. At the same time they reveal how enormously the levels of illumination must be increased to counteract the absorption of light by surfaces of low reflection-factors.

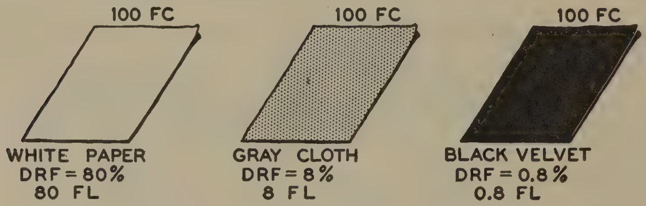


FIG. 14.—A simple lesson in brightness. Under the same illumination—100 footcandles—the brightnesses of the three surfaces in footlamberts (FL) are proportional to their diffuse reflection-factors (DRF). The left-hand surface is 100 times as bright as the right-hand surface because its DRF is 100 times that of the right-hand surface.

In Fig. 14 three common surfaces are represented. They nearly span the entire range of common diffusely reflecting surfaces. They may be visualized, respectively, as white paper, gray cloth and black velvet. If each is illuminated to a level of 100 footcandles their brightnesses are vastly different. The brightness of the white paper is 100 times as great as that of the black velvet.

Now turn to Fig. 15. To make the brightness the same for the three diffusely reflecting surfaces, our only recourse is to increase the footcandles to counterbalance the greater absorption or lesser reflection of light by the gray cloth and by the black velvet. The footcandles necessary to make the brightnesses of the three surfaces equal are indicated for each surface. The importance of diffuse reflection-factor and particularly the relationship of footcandles to footlamberts is emphatically shown. Ten footcandles on the white paper of this printed page is a very moderate level of illumination and the brightness produced is about 8 footlamberts. However, to produce this same brightness on the gray cloth, of Fig. 15, 100 footcandles are required. In the case of the black velvet with a diffuse reflection-factor of less than one percent, 1000 footcandles are necessary.

Figs. 14 and 15 present a very important principle that has been almost entirely ignored in consideration of visual tasks and in lighting for seeing. For many years and until very recently "authoritative" recommendations were 10 footcandles for office work and 20 footcandles for sewing on dark goods. This is striking proof that thought and knowledge, upon which empirical lighting practice has been based, were almost entirely devoid of proper considerations of brightness and of its basic importance in seeing.

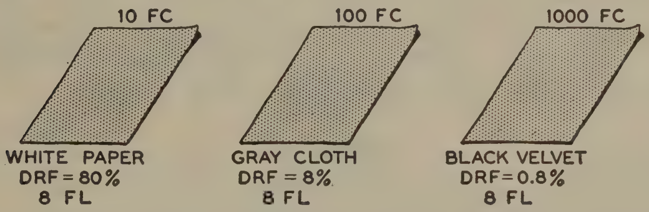


FIG. 15.—The primary purpose of light is to produce brightness. It accomplishes this only through the cooperation of the surface its illuminates. These three diffusely reflecting surfaces are of equal brightness—8 footlamberts—because the levels of illumination from left to right are 10, 100 and 1000 footcandles, respectively.

Office work generally involves seeing tasks whose critical details have high brightness-contrasts with their backgrounds. In other words, office work commonly involves socalled black or near-black details on socalled white backgrounds such as white paper. Sewing on dark goods at best involves fine details on backgrounds of low reflection-factor. From the viewpoint of brightness alone, sewing on dark goods requires 100 or 200 footcandles if the brightness-levels of these visual tasks are to be comparable with those in the office. Still, empirical lighting specialists of the past have not understood these basic facts of brightness.

The science of seeing has eliminated from authoritative codes some of the crude unscientific footcandle specifications of the past. However, throughout the world of everyday seeing those who perform critical tasks involving low reflection-factors, which are just as prevalent as high reflection-factors, are supplied with levels of illumination far from adequate from the viewpoint of this simple factor of brightness. For example, the tasks of seeing of tailor and seamstress in factory, shop or home are inordinately severe due to a lack of illumination adequate even to counteract the low reflection-factors. Brightness-contrast between details and their background is another factor involved which, as will be seen in later chapters, calls for even more footcandles than those necessary to maintain the brightness-level of such tasks equivalent to that of the white paper of this page.

TABLE I

Showing the Illumination in Footcandles (FC) Necessary to Make All These Surfaces, with Diffuse Reflection-Factors (DRF) Ranging from 0 to 100 Percent, Have the Same Brightness—10 Footlamberts

DRF	FC	DRF	FC
100	10	10	100
90	11.1	9	111
80	12.5	8	125
70	14.3	7	143
60	16.7	6	167
50	20	5	200
40	25	4	250
30	33.3	3	333
20	50	2	500
10	100	1	1000

In Fig. 16 is presented a summary of the relationship of footcandles of illumination and footlamberts of brightness. This combines Figs. 14 and 15 in the same diagram for convenient study. It is well worth studying by making comparisons vertically, horizontally and even diagonally. One should engrave this illustration on the memory so that it may be recalled when considering any of the countless tasks of seeing.

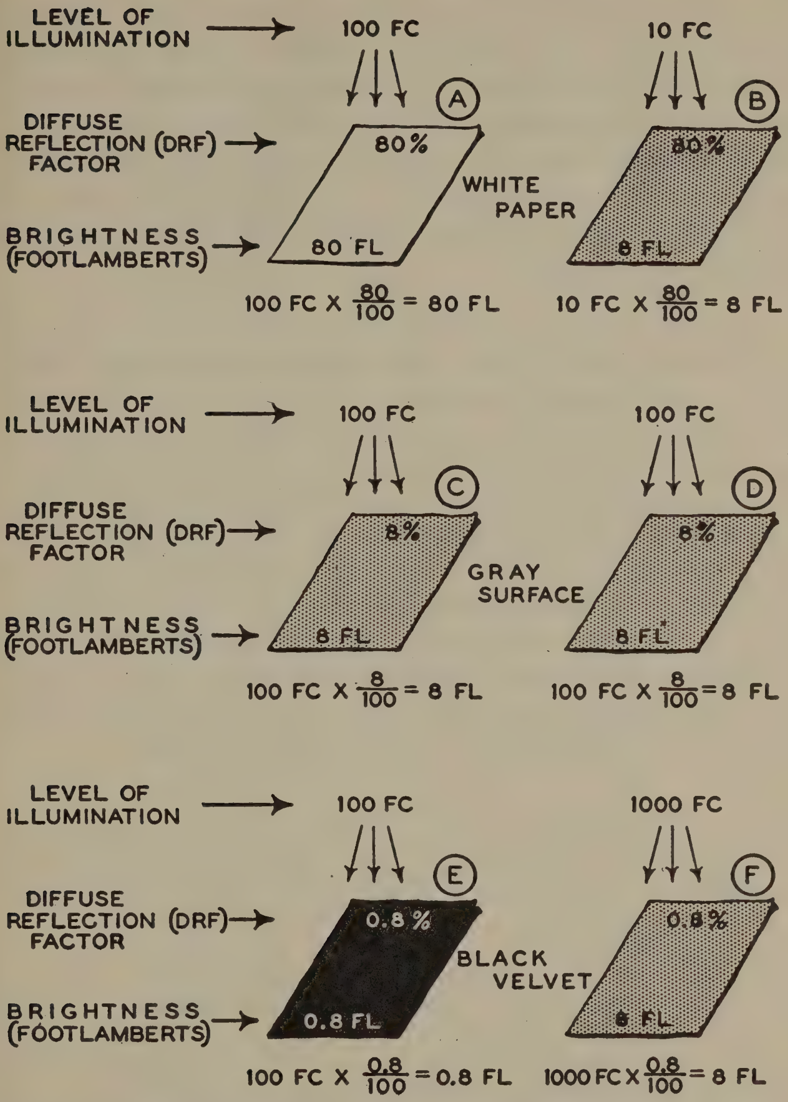


FIG. 16.—A convenient summary of the two preceding illustrations. It is recommended that the reader study it in detail in order to convince himself of the shortcomings and even fallacies of footcandles when considered apart from reflection-factor. Brightness is the goal. For the same brightness of the surface, the levels of illumination range from 10 to 1000 footcandles.

Although it is easy to determine the brightness of a diffusely reflecting surface by multiplying its DRF by the footcandles, Table I should be helpful. It also aids in emphasizing this simple but neglected relationship. In the FC column are indicated the footcandles necessary to make each surface, respectively, have a brightness of 10 footlamberts. This would be the brightness of the white paper of this page if it were illuminated by approximately 12 footcandles.

DIFFUSE REFLECTION-FACTORS

Surfaces vary in their diffuse reflection-factors from nearly zero to approximately 100 percent. Some are readily describable but others, particularly colored surfaces such as paints and fabrics, are not. However, representative ones are included in Table II, for what they are worth in helping to visualize reflection-factors and the resulting brightnesses under any given level of illumination. In the case of paints the diffuse reflection-factors of the dry pigments are presented, for they are more definite than the colored paints in which they are used in many combinations with white, black and other pigments. Obviously the reflection-factors in percent also represent the brightnesses in footlamberts if all the specimens are illuminated to a level of 100 footcandles.

TABLE II

Approximate Diffuse Reflection-Factors (DRF) of Common Materials and Surfaces. Each Value of Reflection-Factor Becomes Footlamberts If All Specimens Are Assumed to Be Illuminated to a Level of 100 Footcandles.

Papers and ink	Percent
White, excellent book	80-85
Newsprint	60-70
Yellow, light	60-70
Greenish tint	60-70
Bluish tint, very light	60-70
Blue, medium	35-45
Blue, deep	5-10
Black	3-5
Black ink, dull	3-5
Black ink, glossy	2

Dry powdered pigments	Percent
American vermilion	14
Venetian red	10
Burnt sienna	10
Raw sienna	30
Golden ochre	58
Yellow ochre	50
Chrome yellow, medium	55
Chrome yellow, light	75
Chrome green, medium	14
Cobalt blue	16
Ultramarine blue	7
Woods, unfinished	
Curly maple	40-50
Oak	30-40
Walnut	10-20
Mahogany	15-20
Stained woods	10-30
Miscellaneous	
Magnesium oxide	95-98
Magnesium carbonate	94-98
White plaster	85-90
White porcelain enamel	65-75
Black wool cloth	1.3-1.6
Black velvet	0.2-0.8
Paints	
White, glossy or flat	80-85
White, water soluble	75-90
Black, very glossy	2
Black, dull	3
Outdoor areas	
Grass and green crops	5-10
Woods in summer	3-5
Barren soil, dry	8-20
Clouds, dense layer	80
Snow, clean	80

BRIGHTNESSES OF OUTDOOR AREAS

It is helpful to know what the brightnesses of typical areas and surfaces are, particularly outdoors. These are the areas under which we and our eyes evolved. Certainly we have become fairly well adapted to them. Statements to the effect that brightnesses equivalent to most of these are harmful are sheer nonsense. Still, apparently without knowing what the brightnesses are outdoors, some persons occasionally state that this or that brightness indoors is too high when actually it is far less than that of a green grass lawn in the full sunlight of midday. For example, this page illuminated by 100 footcandles is only one-fifth or even one-tenth as bright as green grass lawns and fields in full sunlight.

Owing to a state of adaptation to lower brightnesses indoors a given brightness may seem to be brighter. Sometimes, due to dark surroundings indoors, a given brightness may be annoying or even glaring. However, the brightness in itself is not harmful. This emphasizes the importance of proper lighting as well as adequate light.

In Table III are presented some outdoor brightnesses which are commonly in the field of view. Inasmuch as the brightnesses of light-sources and lighting equipment are commonly expressed in candles per square inch, these are also included. The brightnesses of light-sources are discussed in later chapters particularly in connection with glare. A candle per square inch is equivalent to about 452 footlamberts as seen later.

In order to compare these brightnesses with those encountered indoors the last column of values in Table III is presented. These indicate, in each case, the footcandles necessary to produce the same brightness of a common white paper having a diffuse reflection-factor of 80 percent.

The brightnesses presented in Table III are in general the maximum brightnesses for they were determined at midday on a clear day in midsummer. At that time the sun is nearly overhead in the latitude where the measurements were made. As a consequence the areas were receiving the maximum amount of sunlight. Obviously the average values for the entire day are considerably lower. In December, the maximum amount of light received by the earth is also much less. Therefore, the average values may be considered to be less than half those presented in Table III.

TABLE III

Brightnesses of Common Areas Outdoors at Noon on a Clear Day in Midsummer. These Are Expressed in Footlamberts and in Candles per Square Inch. In the Last Column Are Indicated the Footcandles Necessary to Make the Brightness of a White Paper (DRF of 80 Percent) Equivalent in Each Case. One Candle per Square Inch Is Equivalent to 452 Footlamberts.

	Candles per Sq. In.	Footlamberts	Footcandles on White Paper
Deep blue sky	1	450	563
Hazy blue sky	4	1800	2250
Hazy sky near sun	77	35000	43750
Brightest sunlit cloud	20	9000	11250
Green growing crops	1	450	563
Green grass in sun	1.6	700	875
Green grass in shade	0.1	50	63
Woods, average	0.4	180	225
Sunny side of trees	0.8	375	470
Shady side of trees	0.1	60	75
Brick pavement in sun	2	900	1125
Dark soil, dry	1.5	675	844
Barren soil, light	4	1800	2250
Sandy beach, dry	10	4500	5630
White cloth	20	9000	11250
Black cloth	0.5	225	281

It is interesting to note from Table III that a black cloth in full sunlight has a brightness equal to that of a white paper illuminated by about 280 footcandles. Common areas such as sand, soil, green crops, and lawns are as bright as this page would be if it were illuminated to levels of 500 to 5000 footcandles.

It is not suggested that white paper or snow under full sunlight is a comfortable brightness. White paper is an artificial product, devised for our civilized use, and snow in full summer sunlight is so rare geographically that it can scarcely be considered to be a common factor in the environment to which mankind became adapted in the process of evolution. However, the common areas of landscapes and, therefore, their average brightnesses, certainly were commonplace during the later eons of the evolution of life. Even common exposure and experience outdoors have adequately proved the general harmlessness of the brightnesses of most areas in the daytime.

BRIGHTNESS OF THE RETINAL IMAGE

From the viewpoint of seeing, the brightness of the retinal image is more important than the brightness of the object or its background. The pupil of the eye varies in diameter over a somewhat greater range than from one to six millimeters. In the case of the camera, the amount of light admitted to the sensitive film depends upon the area of the aperture. This varies as the square of the diameter. Therefore, the area of the pupil of the eye commonly increases to about forty times its minimum area. Many factors determine the size of the pupil, including the brightness-level, the areas of high brightness in the visual field and the presence or absence of glaring light-sources. All these matters are involved in the science of seeing.

For the present it is of interest to note the difference in the size of pupils of various persons exposed to exactly the same brightness conditions. For example, in Fig. 17 are presented graphically the relative areas of the pupils of 16 adult persons as measured while they read a book illuminated by 10 footcandles with all other conditions constant. Even under these constant conditions the largest pupils were 6.5 times the area of the smallest pupils.

Let us take the subject with the largest pupils as the basic one and consider that he is looking at this page illuminated to a level of 10 footcandles. The retinal image of this page will have a certain brightness in this case. In order for the subject with the smallest pupils to have retinal images of this page of a brightness equivalent to those of the basic subject, this page should be illuminated to a level of 65 footcandles. The average subject should have about 25 footcandles on the page.

As seen in Fig. 27, Chapter VII, the size of the pupil of the eye generally decreases with age. This is another handicap of older eyes.

The size of the pupil is another of many avenues which must be considered if we are to be able to specify light, brightness and lighting on a scientific basis. Such data emphasize in many ways the folly of stating, with the valor of ignorance, that ten footcandles are enough for reading or for even more critical tasks of seeing. One may ask a hundred questions pertaining to the kind of visual task, the size of type or other details, the reflection-factors involved, the status of eyesight and so on. From Fig. 17 one can add another question pertaining to the natural size of the pupils compared to the average.

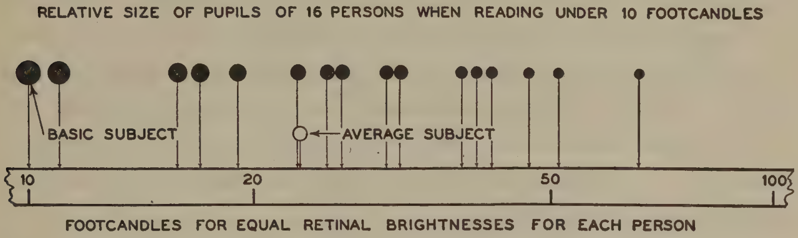


FIG. 17.—The "normal" size of the pupil of the eye varies markedly among persons performing the same task under identical conditions. The brightness of the retinal image is the final important brightness. It varies directly with the area of the pupil. The lower scale indicates the footcandles on the printed page necessary in each case to produce a given brightness of the retinal image.

Naturally in obtaining such data, showing a range of 650 percent in the size of the pupils of 16 subjects exposed to identical brightness conditions, we wondered if the pupil size were related to the absolute sensitivity of the retina to brightness. Of course, it was possible that the persons with the smaller pupils did not need as much light as the average, because their retinas might utilize the light more efficiently. This possibility was tested by a specially designed device and some degree of correlation between pupil size and retinal sensitivity was found.[16] In other words, the sensitivity of the retina to light appears to be greater in general for eyes with naturally small pupils than for eyes whose pupils are naturally large. However, it does not appear that a greater retinal sensitivity to light fully compensates for the pupils that are naturally smaller. Therefore, Fig. 17 stands as still another factor that may be taken into account.

Should general specifications of light and lighting be made for average persons or for those who need it most? Actually the situation for the present is simplified, for very generally the levels of illumination are inadequate for the critical tasks of seeing performed by persons best equipped for seeing. Some attention is being paid to lighting conditions for sight-saving pupils, but more weight should be given to the fact that average vision is subnormal. Certainly old eyes as well as young eyes should be given special consideration.

OTHER BRIGHTNESS UNITS

Inasmuch as there are various systems of units in use there are various brightness units. It is now customary in this country to use the footlambert to express the brightnesses of most reflecting surfaces. However, the brightnesses of light-sources, of portions of lighting equipment, of sky and clouds, and other relatively bright areas are expressed in candles per square inch. This latter unit defines itself. The candlepower of a square inch of luminous surface can be determined just as the candlepower of a source is measured in photometry by comparison with a source of known candlepower.

Suppose, for example, that we cut a hole an inch square in a black cardboard and hold this against a diffusing lamp bulb, or in a position so that a sunlit cloud is visible through the hole. Suppose our photometer indicates that the candlepower of this square inch is equivalent to a light-source of 10 candlepower. Obviously the brightness of the hole—the luminous square inch—would be 10 candles per square inch. At a distance of one foot the maximum illumination would be 10 footcandles. Owing to the socalled inverse-square law the maximum illumination at a distance of 10 feet would be only one-tenth footcandle.

The illumination in footcandles at any given distance from a light-source is computed by dividing the candlepower of the source by the square of the distance from the source. However, it is easy to measure by means of a light-meter.

Fig. 18 provides a simple means of converting brightnesses from one unit to another. The millilambert is a unit of brightness in the metric system. It need not be defined here, but inasmuch as many measurements of brightness are presented in the metric system it is included in the conversion scales of Fig. 18. Obviously the scales can be extended by moving decimal points and adding ciphers. For example, 20 candles per square inch can replace 2 candles per square inch on the middle pair of scales. Obviously the equivalent brightness is approximately 9000 footlamberts instead of 900 on the scale.

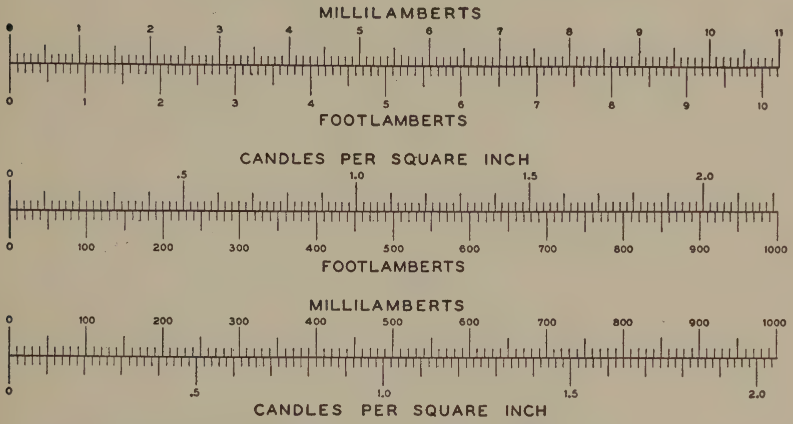


FIG. 18.—The relationships of the three units of brightness in common use. In this country the footlambert is commonly used for designating the brightness of reflecting surfaces. The brightness of light-sources and areas of clouds, sky and lighting equipment are commonly expressed in candles per square inch. One candle per square inch equals 452 footlamberts.

The actual relationships of the three brightness units are as follows:

1 footlambert = 1.076 millilamberts = 0.00221 candle per square inch.
1 candle per square inch = 452 footlamberts = 487 millilamberts.
1 millilambert = 0.929 footlambert = 0.00205 candle per square inch.

For many practical purposes it is sufficient to consider a footlambert equal to a millilambert.

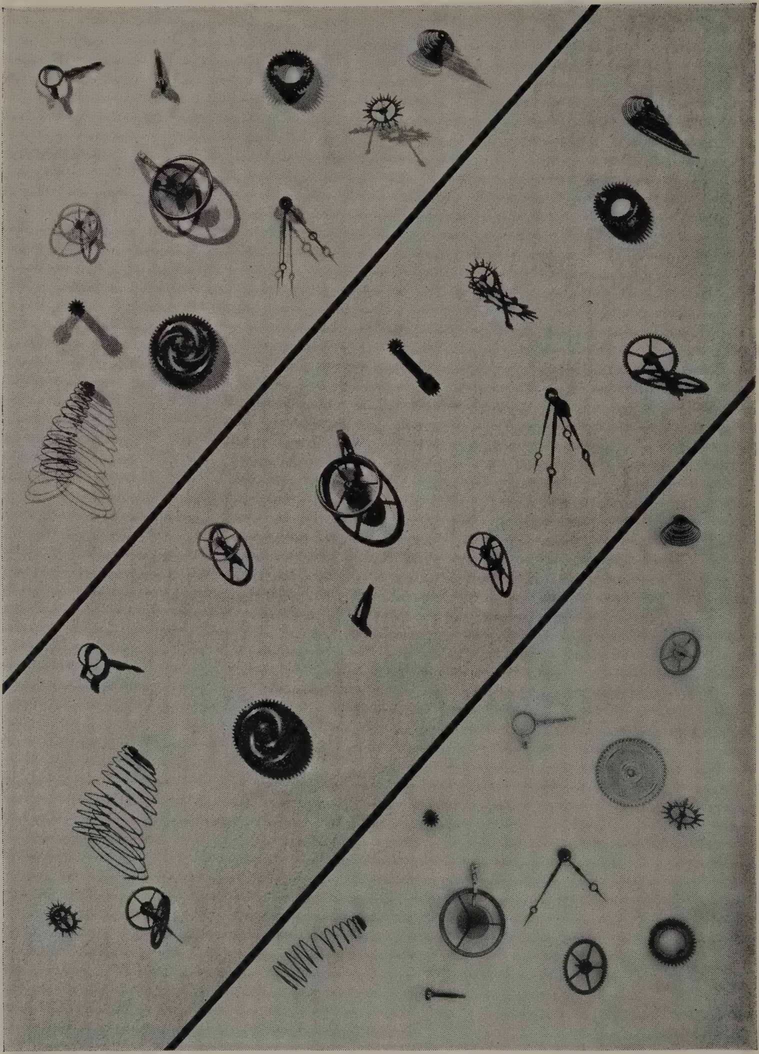


PLATE VII.—The size of details to be seen varies enormously and their visibility is enhanced or hindered by shadows and highlights. Multiple shadows, as in the upper left, are confusing. Single shadows, as in the middle strip, are often helpful. Diffused light, as in the lower right, erases the shadows.

CHAPTER VII

The Role of Size

When examining a critical task of seeing we are generally more conscious of size than of any other factor. This does not mean that it is always the most important factor, for it is not. The minimum size of an object or detail which we can barely see under a given set of seeing conditions is termed, the threshold size. This varies greatly with the brightness-contrast between the object and its background. It varies considerably with the level of brightness or illumination. It varies markedly with the character and magnitude of eye-defects, as anyone who has reached the bifocal stage can testify. In fact, the size of the letters on a test-chart which one can barely read has given size too much importance in seeing at the expense of other factors.

Although it is easy to visualize and to measure the physical size of an object, it is difficult for most persons to interpret physical size into visual size. For example, the average physical size of the type used to print this page is very definite. It is measured in points, a point being approximately one seventy-second of an inch. However, the visual size of this printed matter depends upon its distance from the eyes. At a distance of two feet the visual size of the letters is only half that at one foot. If one is to understand the role of size in vision and in seeing, it is very essential to master the meaning of visual size, to think in terms of it, to memorize some of the magnitudes of threshold size presented in this and other chapters, and to marshal all this knowledge when appraising visual tasks.

Visual acuity, discussed in detail in Chapters X and XI, is a term used to denote the ability to distinguish fine details. Actually it is the sensitivity of the visual sense to the size factor. It is proportional to the reciprocal of threshold size. For example, assume that under given conditions, a person with subnormal vision can barely distinguish a detail twice as large as the smallest that a person with normal vision can see. The visual acuity of the person with subnormal vision is one-half that of the one with normal vision. The two visual acuities may be rated, respectively, as 50 and 100.

PHYSICAL AND VISUAL SIZE

In Fig. 19 is illustrated the relation of visual size to the combination of physical size and distance. Suppose we are looking at a long row of telephone poles. Obviously they appear smaller and smaller as they become more and more distant. Suppose they are equally spaced and we stand at the same distance from pole 1 as it is from pole 2. The poles are all the same height—same physical size—but their visual size rapidly decreases with distance. If the visual size of pole 1 is designated as 100, the visual size of pole 2 is 50, pole 3 is 33, pole 4 is 25 and pole 5 is 20. In other words, pole 5 being five times as far away as pole 1, it is only one-fifth as large visually.

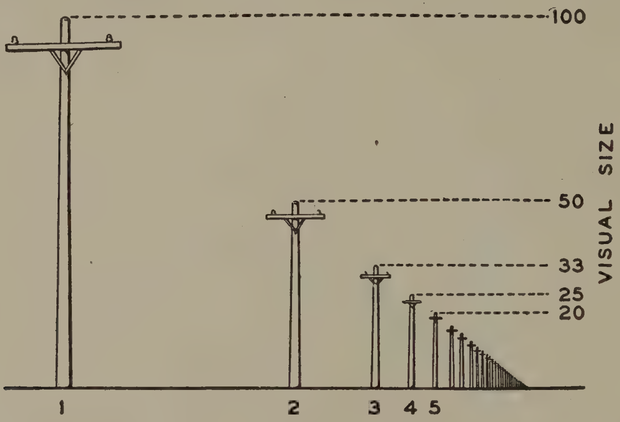


FIG. 19.—Poles of equal height and spacing decrease in visual size as the distance from the observer increases. Their physical size remains constant but it is their visual size which is important in vision and seeing. Pole 5 is five times as far away from the observer as pole 1. Therefore, its visual size is only one-fifth that of the nearest pole.

To counteract the decrease in visual size due to distance, it would be necessary to increase successively the size of the poles as illustrated in Fig. 20. To have all the poles equal in visual size to the first pole which in this case is assumed to have a height of 25, the heights of the four poles would have to be respectively 25, 50, 75 and 100. In other words, the physical size of the pole at 400 feet would have to be four times that of the pole at 100 feet in order for both to be equal in visual size.

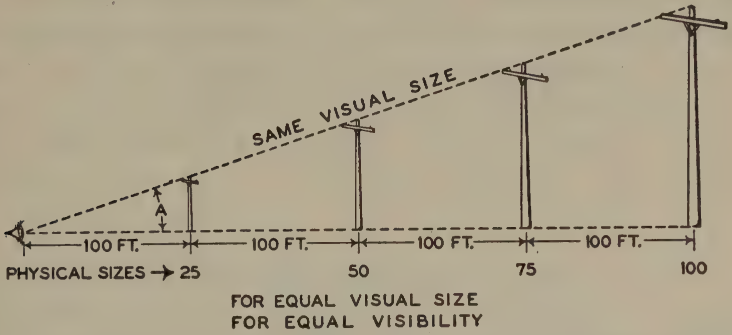


FIG. 20.—If the poles were to be equal in visual size, their actual physical size would have to increase in the same proportion as their distance from the observer. If the first pole were 25 feet in height, the fourth pole would have to be 100 feet in height.

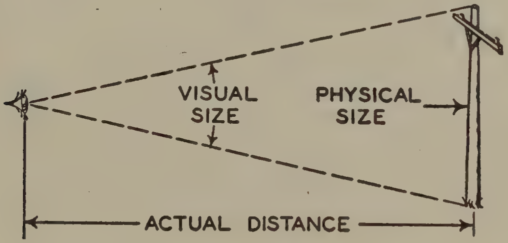


FIG. 21.—Visual size is the angle subtended at the eye by the physical object at a distance. Actually the smallest visual sizes that are visible under common conditions are so small that they are measured in minutes of visual angle. For example, 0.004 inch at a distance of 14 inches from the eye subtends an angle of about one minute at the eye.

Thus we are prepared with the aid of Fig. 21 to understand that visual size is measured by the angle subtended at the eye by the object. Inasmuch as the threshold sizes of objects are very small, they are conveniently measured in minutes of visual angle or sixtieths of a degree. Therefore, in dealing with the size factor in vision and seeing, we speak of an object in terms of the angle subtended at the eye which may be one minute, five minutes, or any other visual angle. It is very important that visual size be understood and it is easy to learn to visualize the sizes when described in minutes. Incidentally, the threshold size of a critical detail (black on a white background) is about one minute for persons with normal vision and under seeing conditions commonly encountered in our indoor work-world.

SIZE OF TYPE AND READING DISTANCE

Owing to the importance of understanding what visual size means, let us apply the same reasoning to printed matter, such as is represented by this page. Suppose we had a square of reading matter printed with 12-point type and we held it 10 inches from our eyes. The effect upon the size of type is illustrated in Fig. 22. If we increased the distance to 15 inches, we would, in effect, decrease the size of type about one-third or, as expressed in points, to about 8-point. This is emphatically true even though it is difficult to "see" that the type of this page is visually only half the size at a distance of two feet that it is at a distance of one foot. Hold this printed page successively at distances of one foot and two feet and note how difficult it is to visualize the great changes in the visual size. This will reveal one reason for generally overlooking this factor in seeing.

Returning to Fig. 22, suppose that four specimens of 12-point type are held, respectively, at distances of 10, 15, 20 and 30 inches. In effect the relative sizes of type are, respectively, 12-point, 8-point, 6-point and 4-point. This is literally true when this page is properly considered as a visual task. In other words, if we were reading the type of this page at a distance of 14 inches and then increased the distance to 30 inches, we would be reading the equivalent of about 5-point type—a size of printed matter that we would not think of reading for long periods. Incidentally, the specimens of type illustrated in Fig. 22 are actually of the sizes indicated. They afford a means of visualizing sizes of type.

To view the matter in another way, suppose we have a page of reading matter printed with 4-point type as illustrated in Fig. 23. This is smaller than we would care to read for long periods. In fact, 3-point type printed with black ink on white paper is about the smallest that can be read at a distance of 14 inches under good seeing conditions. Suppose the 4-point type were held at a distance of 10 inches from the eyes, which we would likely do if we had to read a page of it. In order to maintain the same visual size for different reading-distances, the physical size of the type would have to be increased as indicated in Fig. 23. For example, the visual size of 12-point type at a distance of 30 inches is roughly the same as that of 4-point type at a distance of 10 inches. It is seen that for distances of 10, 15, 20 and 30 inches, the actual type-sizes of 4, 6, 8 and 12 points, respectively, are roughly equal in visual size to the very small 4-point type at a distance of 10 inches.

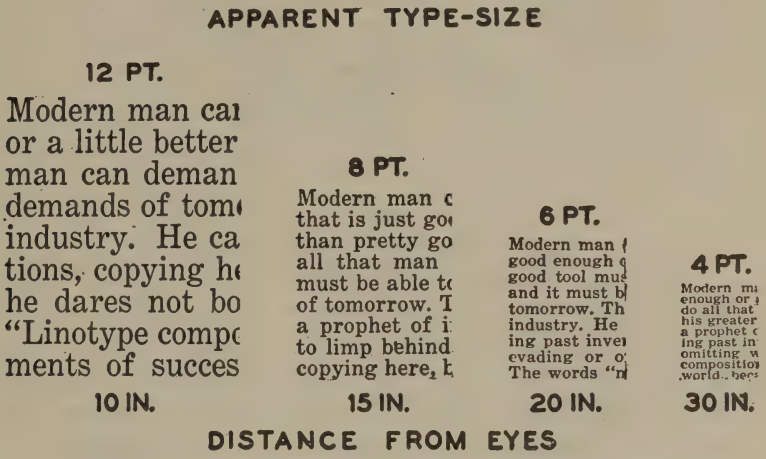


FIG. 22.—Illustrating the dependence of visual size upon physical size and distance from the eye. Hold this illustration 10 inches from the eye and note the size of the 12-point type. Actually if the patch of 12-point type is moved away to a distance of 30 inches from the eye, its visual size becomes equivalent to approximately 4-point type. Holding the illustration at 10 inches from the eye, each patch of type illustrates the actual visual size of 12-point type at the distances indicated, respectively.

Actually the design of type involves various factors including the "feeling" of the designer. Design involves "tempering" which is somewhat analogous to what is done to the mathematical scale of pitch to produce the "musical" scale. For these reasons, a 12-point type is not necessarily exactly twice as large as a 6-point type. However, Figs. 22 and 23, and the discussions of them, are sufficiently accurate for our present purpose.

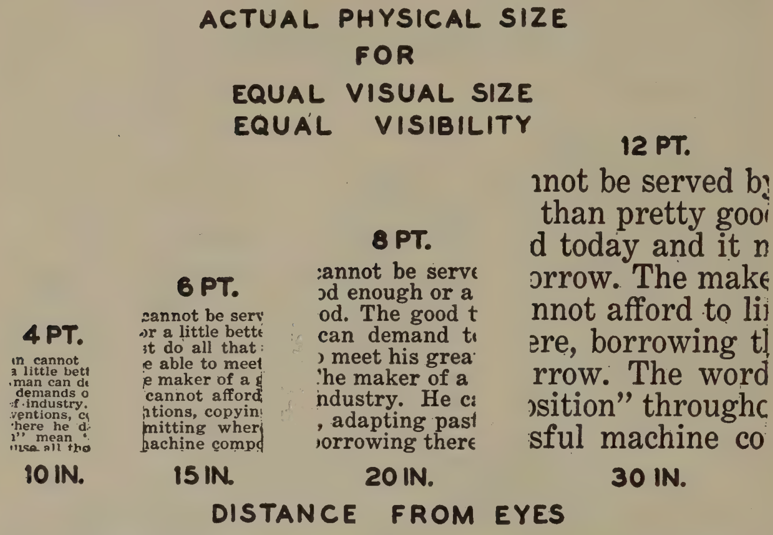


FIG. 23.—This illustration is the reverse of Fig. 22. Holding the illustration at 10 inches from the eye, the 4-point type has a given visual size. As the distance increases, the size of the type must be increased to have the same visual size as the 4-point type at 10 inches.

Even though the 12-point type, at a distance of 30 inches from the eye, appears much larger than the 4-point type, at a distance of 10 inches, it is an illusory effect. We know that the physical size of one is approximately three times as large as the other. In trying to visualize the two visual sizes, we cannot overcome this "knowledge" and we are victims of an illusion. In vision and seeing there are many illusions which commonly lead the uninitiated astray.

THRESHOLD SIZE

This is the term given to the smallest size of an object or detail which can just be recognized under a given set of seeing conditions. Threshold size varies with other factors as indicated in Chapter V. It varies considerably with the level of brightness or for a specific task with the level of illumination. It varies greatly with brightness-contrast. It does not escape the influence of the time-factor, where time is limited, as it is in many tasks where speed of seeing is involved. It varies markedly with the degree of glare from light-sources. Results of all these influences are presented in detail, particularly in Chapters VIII, IX, X and XI.

For the present let us be certain that we have a clear idea of what visual size and threshold size mean. Visual tasks may consist of simple objects, complex forms, or groups of the latter of which the printed words and lines on this page are a specific example. In addition to the actual recognition of an object, seeing often involves distinguishing the mere presence of an object. This is commonly true in driving on the highway at night and also in many tasks of inspection. However, our viewpoint is chiefly confined to critical seeing and, therefore, to the recognition of objects and details with a high degree of certainty. This kind of seeing very generally involves complex objects which necessitates the separation—resolution—of two or more details.

In Fig. 24 is illustrated the fundamental test-object which was originated in our laboratories about four decades ago and has been in continual use throughout that period. As a consequence we have an enormous amount of data properly related by the use of the same test-object. It will be seen that it is difficult to relate with accuracy data which have been obtained with different test-objects. These are adequate reasons for not introducing data by others. However, there is also the important fact that no other data are available which are adequate in continuity, range and variety under standardized conditions, for establishing the relationships of the socalled fundamental factors. Our researches have not only established these relationships with the same test-objects, but have also invaded various byways with the same techniques. This is a very important essential in any attempts to coordinate results of researches.

In Fig. 24 the test-object is shown to consist of two parallel bars, separated by a space, *S*, equal in width to each bar. Actually, the test-object may be visualized as a square with the middle third absent. The entire test-object is easy to describe; and of still more importance, it results in a simple completely describable critical detail. The visual size of this critical detail is indicated by the visual angle *A* subtended by the width of the space *S*. In actual use the line of sight is perpendicular to the plane of the test-object. The parallel bars are not confined to black on a white background. This is a limiting case which when adhered to entirely, as has been true of the test-charts of the eyesight specialist, leads to inadequate conceptions of visual tasks and to grossly erroneous conclusions in regard to threshold size, as influenced by levels of illumination and brightness, by various degrees of contrast in brightness between object and background and by other factors. Threshold size is enormously greater, for example, for a low brightness-contrast between object and background.

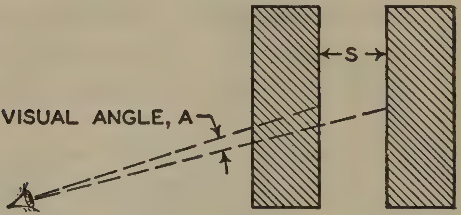


FIG. 24.—This parallel-bar test-object has been in use in our laboratory for four decades. The visual size is the visual angle *A* in minutes subtended by the width of the space *S* at the eye when line of sight is perpendicular to the plane of the test-object.

The parallel bars are reproduced in a series of grays from a very light one, approaching the white of the background, to a very dark one which is commonly termed, black. In fact, the limiting case of absolute black is obtained by silhouetting the bars against the white background or by cutting them out of the white background and backing them with a large velvet-lined light-proof box. Such a complete series of grays is necessary for a complete study of threshold size as influenced by the variety of combinations of factors encountered in everyday visual tasks.

Incidentally, over a large range of brightnesses the black bars on a white background yield sensibly the same results as white bars on a black background.

As a further refinement in research the parallel bars can be altered in position. Vertical, horizontal and two diagonal positions are convenient ones which can be controlled automatically. Thus the researcher can be certain that the subject not only sees but distinguishes the test-object. In addition to this, the test-object can be exposed automatically for any period of time. Control is a vital factor in research.

These glimpses behind the scenes are presented for the purpose of indicating the care and control which must be exercised and the need of precision devices if dependable and accurate results are to be obtained. It is interesting to compare these procedures with those of the common test-chart as discussed in Chapter XI. Through such precision and control, accurate data pertaining to threshold size have been obtained. The common test-charts may be adequate for their specific purposes but these do not include establishing the fundamentals of the science of seeing.

In Fig. 25, one may further compare the complexity of even a common letter with the simplicity of the parallel bar test-object. What is the size or what are the sizes of the critical details of the letter or of the broken circle? In the case of the letter *E* no simple answer can be given which is accurate or complete. The broken circle presents a less complicated test-object but even this is not simple, if for no other reason than its lack of symmetry.

We have often been asked why we did not use "practical" objects of everyday visual tasks in our researches. From the foregoing glimpses, the answer should be obvious. Socalled practical objects from everyday tasks are impracticable in the extreme. Even the individual letters in a line of letters on the common test-chart vary in size, number and character of critical details. They vary markedly in visibility. A line of letters or of other complex characters is too crude for research purposes regardless of their practicability for testing vision. Even in such usage they are not precision devices.

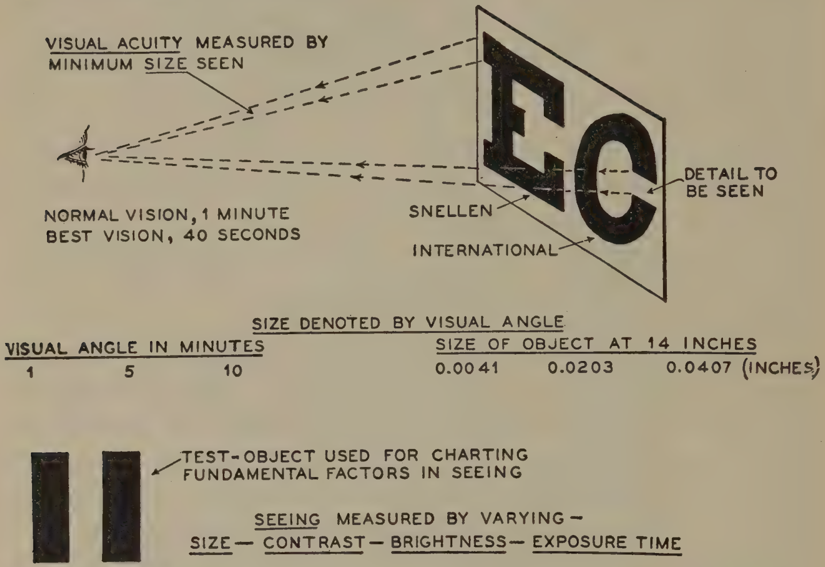

VISUAL ACUITY MEASURED BY
MINIMUM SIZE SEEN
NORMAL VISION, 1 MINUTE
BEST VISION, 40 SECONDS
SNELLEN
INTERNATIONAL
DETAIL TO BE SEEN
SIZE DENOTED BY VISUAL ANGLE
VISUAL ANGLE IN MINUTES
1 5 10
SIZE OF OBJECT AT 14 INCHES
0.0041 0.0203 0.0407 (INCHES)
TEST-OBJECT USED FOR CHARTING FUNDAMENTAL FACTORS IN SEEING
SEEING MEASURED BY VARYING—
SIZE— CONTRAST— BRIGHTNESS— EXPOSURE TIME

FIG. 25.—Illustrating the critical details of various test-objects. Their visual sizes are complicated in most cases. It is definite for the parallel-bar test-object which is simple, symmetrical and easily describable. Unless otherwise stated, this was the test-object used in obtaining much of the fundamental data presented in other illustrations.

It is hoped that the reader will bear these facts and principles in mind as he tries to analyze various visual tasks or to dissect them into their fundamental factors. He will find dissection to be very difficult in many apparently simple cases and even impossible in most cases. Then he should be ready to fully appreciate the value of the fundamental data which are presented in these chapters. Furthermore, such experience should also emphasize both the scientific and practical value of a visibility meter and visibility measurements as discussed later and as applied to everyday tasks of seeing.

BACKGROUND AND THRESHOLD SIZE

The contrast in brightness between the object and its background has been mentioned as a very important fundamental factor. It is discussed in Chapter VIII in considerable detail where many data are presented pertaining to its great influence upon the visibility of a given object or task, or upon the size of an object if that object is to be barely visible. Therefore, that aspect is avoided here due to the simple condition of viewing our standard test-object against backgrounds of different diffuse reflection-factors under the same level of illumination. Actually this results in a series of backgrounds of different brightnesses.

In Fig. 26, the effect of the reflection-factor or brightness of the background upon the threshold size is strikingly illustrated. In obtaining these data the test-objects were "black" with a diffuse reflection-factor of 3 percent. The test-object may be visualized as being viewed against backgrounds varying in diffuse reflection-factor from 3.4 percent (very dark gray or nearly black) to 80 percent (socalled white). Three levels of illumination, 1, 10 and 100 footcandles, were applied to the backgrounds and a series of threshold sizes is shown for each level of illumination. As in all other cases, unless otherwise stated, a representative group of subjects with normal vision was used.

Beginning at the right-hand end of Fig. 26, we have the equivalent of objects printed with black ink on white paper. With such a condition the threshold size—the size of a barely recognizable object—is smallest, but it varies with the level of illumination. As the background decreases in reflection-factor, the brightness is also decreased for any given level of illumination. Progressing from right to left it is seen that threshold size gradually increases with decreasing reflection-factor of the background. It rises precipitously as the reflection-factor decreases below 10 percent.

For the range shown it is seen that the threshold size increases nearly four times. In other words, when the black object (DRF = 3 percent) is viewed on the background of lowest diffuse reflection-factor (DRF = 3.4 percent) it must be four times as large, to be barely recognized, as when it is on a white background. The former case is representative of many tasks such as sewing on dark goods and the latter case is representative of such a task as reading these words. Between, and including these two extremes, are countless tasks of our everyday world of seeing.

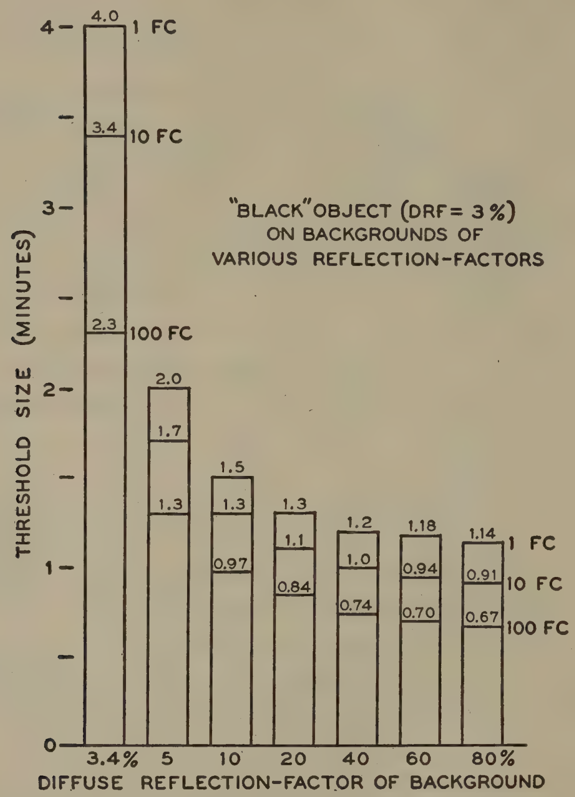


FIG. 26.—Showing the minimum size of a black object to be just barely visible against backgrounds of various reflection-factors and illuminated to three levels—1, 10 and 100 footcandles.

The effect of level of illumination is obvious. The threshold size is nearly twice as large for the one-footcandle level as for the

100-footcandle level. Actually, the minimum size of an object to be barely distinguishable generally must be about 70 percent larger under an illumination of one footcandle than it is under an illumination of 100 footcandles.

This fact, and many others, can only be established by the use of precision test-objects and carefully controlled techniques. This illustrates the most outstanding factor in the development of knowledge by modern scientific methods. Knowledge is founded upon measurements and it increases in proportion to the precision and sensitivity of instruments and methods. If one follows the progress of modern science along any avenue, the truth of this statement becomes obvious. The knowledge of a Newton is gradually refined by more precise measurements until an Einstein is needed to refine the whole. And so on. This is equally true of the science of vision and the more extended science of seeing.

THE IMAGE ON THE RETINA

For any external brightness, such as this page, the retinal brightness varies with the size of the pupil. The size of the pupil varies considerably with the brightness and brightness-distribution in any scene before us. The size also varies greatly for different individuals under exactly the same brightness conditions, as illustrated in Fig. 17, Chapter VI.

Naturally the size of the pupil has received some attention from the viewpoint of the character of the retinal image as well as of its brightness. It has been erroneously assumed that a small pupil increases the ability to see small objects. It is true that a small aperture increases the "definition" or "depth" of focus in the case of the camera. A small pupil does this for the eye. However, in drawing that conclusion another factor is too commonly ignored. The "resolution" of a lens increases with the size of the aperture. By resolution is meant, not the clearness of focus, but the ability of an optical system to separate or resolve two very small details, adjacent to each other, into two distinct images.

In ordinary photography we are not greatly concerned with resolution although we are in special applications. However, we are much concerned with that factor in critical seeing wherever it is necessary to distinguish details which are close together. For this reason telescopes of larger and larger optical diameters or apertures are built for astronomical purposes. For a similar reason large pupils are advantageous in addition to their effect upon the brightness of the retinal image. In other words, definition increases as the pupil decreases in size but resolution decreases. This is the probable explanation of the fact that threshold size, or the ability to see fine detail, does not vary for much of the middle range of pupil size. This is illustrated in Chapter X.

Only a small area of the retina—the fovea—is highly useful in distinguishing fine details. An image of our parallel bar test-object, illustrated in Fig. 24, just about covers the fovea when the overall visual size is 60 minutes. Inasmuch as the critical detail of this test-object is the width of the space between the two parallel bars, the visual size is actually 20 minutes, when the image of the entire test-object approximately covers the entire fovea. For this reason we generally confine discussions of threshold sizes to the range from 0 to 20 minutes of visual angle.

AS EYES GROW OLDER

The pupil of the eye, as measured under standardized brightness conditions, grows smaller with age. Obviously this decrease in size affects the brightness of the retinal image which in turn affects seeing. As the eyes grow older there is also a definite increase in threshold size, or decrease in the ability to distinguish fine details.

These two results of increasing age are illustrated in Fig. 27 in which are indicated the relative sizes of the pupil at various ages. The series of letters represents the relative sizes necessary for barely recognizing the letter under standardized conditions. It is seen that the letter must be about 30 percent larger to be barely visible at 60 years of age, on the average, than at 20 years of age. This diagram was plotted from various summaries and may not accurately represent any individual case. However, it pictorializes two facts of consequence that should be taken into account in analyzing seeing conditions and in specifying aids to seeing.

Skill and experience increase with age and there are adequate aids to seeing which can be extended to those whose vision is dulled by age. There are many old persons whose eyesight, even with eyeglasses, has failed to the point that they have given up reading and other critical tasks of seeing. Many of these have been greatly aided, to their own surprise and that of their eyesight specialist, by providing unusually good lighting and seeing conditions.

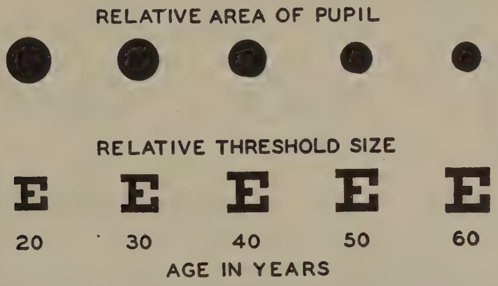


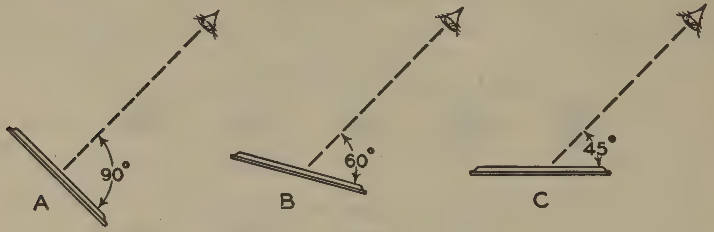
FIG. 27.—Illustrating the decrease of pupil size and the increase in threshold-size (decrease in visual acuity) with increasing age.

POSITION OF THE VISUAL TASK

We have seen how the distance of the object or task affects visual size. This effect is enormous in the case of critical visual tasks within arm's reach. We do not want the work too close to the eyes nor do we want it any farther away than necessary. The matter of visual size as it is affected by distance cannot be overemphasized.

There is another aspect of the position of the work which is often neglected. This is illustrated in Fig. 28 by three positions of a printed page. For a given distance, the visual size of the printed matter is at a maximum when the line of sight is perpendicular to the printed page, as illustrated in position *A*. As the page is inclined more toward the horizontal, the visual size of the printed matter—in effect, the type-size—decreases. In position *C*, which corresponds to a printed page lying on the horizontal plane of a desk, the type-size is only 70 percent of its value in position *A*.

These data were obtained by actual visibility measurements as described in a later chapter. From positions *A* to *C* the equivalent type-size is reduced from 10-point to 7-point. The latter is less than the average size of newspaper body-type. This decrease in type-size and visibility can be counteracted by increasing the level of illumination. To maintain the visibility produced by 10 footcandles on the printed matter in position *A*, it is necessary to provide 25 footcandles in position *C*. This illustrates another of many practical applications of visibility measurements and of scientific specifications of footcandles on the basis of these measurements combined with other knowledge of seeing conditions.



	POSITION OF PRINTED PAGE		
	A	B	C
EQUIVALENT TYPE-SIZE IN POINTS	10	8.5	7
RELATIVE VISIBILITY (PERCENT)	100	85	70
FOOTCANDLES FOR EQUAL VISIBILITY	10	15	25

FIG. 28.—The effective size of type on a printed page decreases markedly with the angle of the line of sight. Consequently, the visibility of the printed matter and also the footcandles necessary to maintain a given standard of visibility vary with the position of the printed page.

EQUIVALENT VISUAL AND PHYSICAL SIZES

Although in the science of seeing we are concerned with visual size, expressed in minutes visual angle, in everyday work we deal with physical sizes, expressed in feet, inches and even thousandths of an inch. In the world of seeing within arm's reach, threshold visual sizes are matters of thousandths of an inch. For example, in Fig. 26 the values of threshold size cover a range from 0.67 to 4 minutes of visual angle. If one wishes to visualize or demonstrate a visual size of one minute it is only necessary to view a wire about four-thousandths of an inch in diameter at a distance of 14 inches. Obviously, the left-hand scale of Fig. 26 may be transformed into physical size (thousandths of an inch at a distance of 14 inches) by multiplying its values by four.

The limits of visual size, in which we are generally interested, are from 0.5 to 20 minutes. If one wishes to compute the visual sizes in minutes visual angle he may do so by the following simple formula,

$$S = 0.0002909DA$$

S is the actual physical size in the same unit as D which is the distance from the object to the eye, A is the visual size in minutes of visual angle subtended at the eye by the object.

Some equivalents of visual and physical size are presented in Table IV for a range of visual size from one to 20 minutes. The physical sizes are given in thousandths of an inch for four distances of the object from the eye—10, 15, 20 and 30 inches. It is seen that all the physical sizes are confined to a range from about 3 to 175 thousandths of an inch.

A few ordinary objects have the following relationships when viewed at a distance of 14 inches:

The distance between the dot and the body of the letter *i* for a common 6-point type is about 0.007 inch. The visual size of this space at 14 inches is 1.7 minutes.

For a certain 12-point type the values are approximately 0.026 inch and 6.4 minutes, respectively.

The width of the eye of a needle of medium size is about 0.019 inch. Its visual size at 14 inches is 4.7 minutes. For a small needle the values are 0.01 and 2.5 minutes, respectively.

A division line, about 0.007 inch wide, on a metal rule has a visual size at 14 inches of 1.7 minutes.

The space between the dots constituting the pattern of moderate density made by a half-tone 65-screen was found to be about 0.014 and its visual size at 14 inches is 3.5 minutes. For a half-tone 120-screen the values were about 0.007 inch and 1.7 minutes.

TABLE IV

The Relationship Between the Visual Size of an Object and Its Physical Size at Various Distances from the Eye.

Visual Size Is Expressed in Minutes of Visual Angle Which the Object Subtends at the Eye.

Physical Size Is Expressed in Thousandths of an Inch.

Visual Size (Minutes)	Physical Size of an Object in Thousandths of an Inch. At Various Distances (Inches) from the Eye.			
	10 in.	15 in.	20 in.	30 in.
1	2.9	4.4	5.8	8.7
2	5.8	8.7	11.6	17.4
3	8.7	13.1	17.4	26.2
5	14.5	21.8	29.1	43.6
7	20.4	30.5	40.7	61.1
10	29.1	43.6	58.2	87.3
20	58.2	87.3	116.4	174.5

SIZE OF DISTANT OBJECTS

Many objects must be viewed at distances beyond arm's reach. On the highway and on the sea these distances extend to many miles. To cover this range there are listed in Table V the viewing-distance and actual physical size which, in each case, results in a visual size of one minute. Obviously, for a larger visual size, the physical size at any specific distance is multiplied accordingly. For example, a visual size of five minutes is obtained by multiplying the value of physical size by five or by dividing the distance by five. Incidentally, for the small range of visual angles subtended at the eye—0 to 20 minutes—proportionality can be assumed without appreciable error.

It is seen that at a distance of one mile, a physical size of 1.5 feet (actually 18.43 inches) subtends a visual angle of one minute. Inasmuch as this is commonly the threshold size for persons with fairly good vision, one may conclude that two adult human beings separated by a distance of 18 inches would be distinguishable as two objects at a distance of one mile, if the background were suitable in brightness and devoid of pattern. The space between them is the critical detail. Inasmuch as the level of illumination outdoors in the daytime is very high, the threshold size for persons of normal vision is actually much less than one minute. Therefore, the two adult persons can be distinguished as two objects if they are separated a foot or even less—provided the background is suitable.

TABLE V

The Distances of an Object from the Eye and the Corresponding Physical Sizes of the Object Which Produce a Visual Size of One Minute.

One Minute Is Commonly the Threshold Size for Persons with Normal Vision and Ordinary Seeing Conditions. (See Fig. 24.)

For Any Other Visual Size, 20 Minutes for Example, the Physical Size Is Multiplied by 20 or the Distance Is Divided by 20.

Distance of Object from the Eye	Physical Size of the Object
1 foot	0.00349 inch
2 feet	.00698 inch
5 feet	.01745 inch
10 feet	.0349 inch
50 feet	.1745 inch
100 feet	.349 inch
200 feet	.698 inch
500 feet	1.745 inches
1000 feet	3.49 inches
2000 feet	6.98 inches
1 mile	1.5 feet
2 miles	3.0 feet
10 miles	15.3 feet
20 miles	30.7 feet

CHAPTER VIII

The Importance of Brightness-Contrast

The various factors which comprise a visual task are so entwined that any attempt to treat each separately leads to some unavoidable repetition. This may be monotonous and even annoying to the reader. However, even this unavoidable repetition has some virtue, for it should aid in developing a better understanding of each fundamental factor. As one who has spent several decades in researches in seeing, and in interpreting the results into many avenues of everyday seeing, the author knows the need for repetition even where it is avoidable.

If one critically examines any visual task, its immediate surroundings, and the entire visual field, he will find many factors which affect visibility and ease of seeing. These are discussed in their turn as we proceed through these chapters. Eliminating for the present the surroundings and every factor excepting those inherent in the visual task, one still finds three factors entwined. They are size of details, brightness-contrast between details and their background, and the brightness of the background or general brightness-level of the visual task. There may be present the complications of color but, in the interest of simplification, color has been arbitrarily eliminated from these early chapters.

Even with this simplification, this page, or any other visual task, involves brightness, size, and brightness-contrast. Time also becomes a factor when one reads this page or performs any other more or less continuous task of seeing. However, the time factor is eliminated from this discussion for it was present as a constant in the highly controlled researches which yielded the basic data presented in these chapters.

Of the three factors, brightness-contrast influences visibility and ease of seeing out of all proportion to the relatively meager

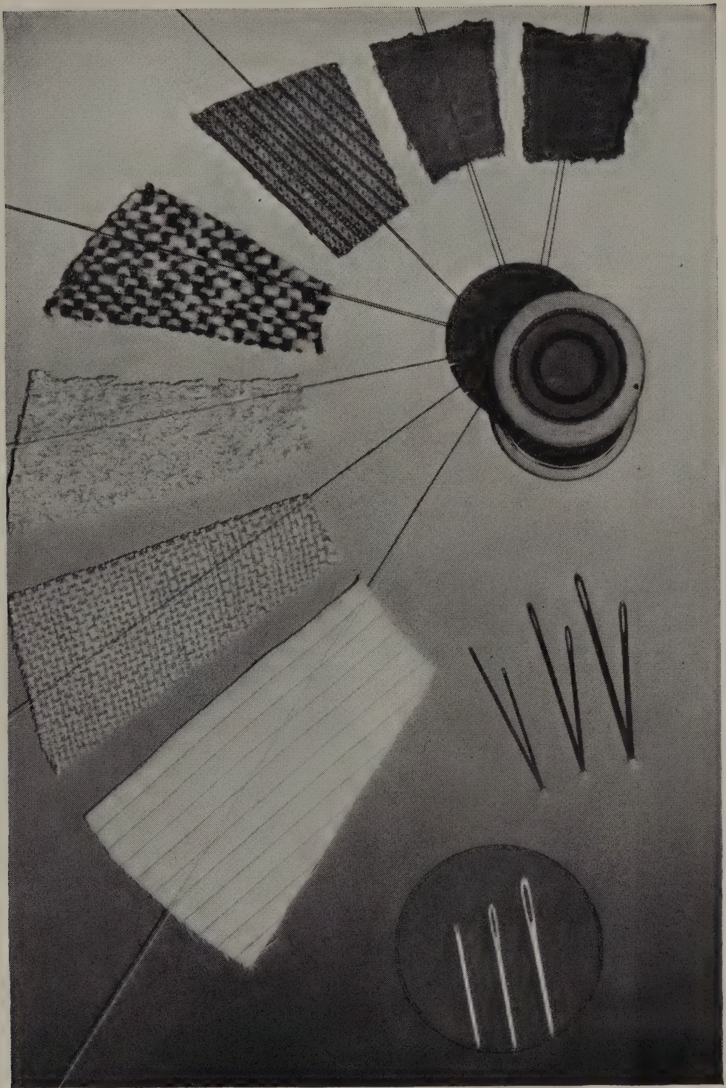


PLATE VIII.—The lower three threads are white and the upper four are black. Their visibility is largely a matter of brightness-contrast with their backgrounds. Other factors—size, shadows and confusing patterns—are also illustrated.

attention it has received in everyday seeing. It is even more neglected than brightness, partially because it involves two measurements of brightness—those of the object or critical detail and of its background. The measurement of the brightness of a detail of small visual size is relatively more difficult than the measurement of the brightness of a relatively large area. For example, the brightness-contrast between the inked letters on this page and their paper background is determined by the brightnesses of ink and paper and the measurement of the brightness of the small letters is quite difficult.

Brightness-contrasts in visual tasks themselves are favorable, but there are others that are unfavorable.[17] These might better be termed, contrast-ratios, to distinguish them from brightness-contrasts inherent in the visual task—details and their background. An example of unfavorable brightness-contrast is that between this printed page and its immediate surroundings. Other examples are the brightness-contrasts between a bright light-source or lighting equipment and its immediate surroundings. If these brightness-ratios are too great, they affect both visibility and ease of seeing. Some of these brightness-ratios are annoying. In the case of light-sources or excessively bright lighting equipment, we are concerned not only with the brightness-ratio but also with the magnitude and area of the offending brightness. In other cases brightness-ratios that are not obviously offensive have been proved to be undesirable. These are discussed in chapters dealing with glare, surroundings and specular reflection.

EXPRESSING BRIGHTNESS-CONTRAST IN PERCENT

After the brightnesses of critical details and their backgrounds are determined, one is confronted with the definition of brightness-contrast and how it may be computed. There are limitations to this method of expressing brightness-contrast in percent, but as long as we confine our considerations to the details of the visual task, the method is practicable and a very useful one. It becomes impracticable in dealing with a bright light-source or a highlight due to specular reflection, for example, when seen against any common background. However, in this chapter we are concerned with favorable brightness-contrasts inherent in every visual task. In this realm, visibility and ease of seeing are increased by increasing brightness-contrast. This page of printed matter is an example of high brightness-contrast between object and background. If the page were dyed a very dark gray it would be representative of many visual tasks in which the brightness-contrast between the critical details and their background is low.

With these limitations in mind, our consideration of brightness-contrast is simplified and we can compute it by means of a simple formula.

For objects whose brightnesses are less than that of their background, the brightness-contrast in percent is equal to

$$\text{BC} = 100 \times \frac{\text{Brightness of background} - \text{Brightness of object}}{\text{Brightness of background}}$$

It is obvious that when the brightness of the object is low compared with that of its background, as in the case of this printed page, the brightness-contrast is high.

It is equally obvious that when the brightness of the object is high compared with that of its background, the brightness-contrast is low.

It is also obvious that the entire range of brightness-contrasts extends from 0 to 100 percent. The lower limit is represented by an object whose brightness is not perceptibly different from that of its background. The upper limit is reached when a perfectly black or absolutely non-luminous object is viewed against a background of any brightness.

If the object is brighter than its background, one merely interchanges the object and the background in the foregoing formula. The brightness-contrast in percent is then equal to

$$\text{BC} = 100 \times \frac{\text{Brightness of object} - \text{Brightness of background}}{\text{Brightness of object}}$$

A common example of such tasks are words written with "white" chalk on a "blackboard."

DIFFUSELY REFLECTING OBJECTS AND BACKGROUNDS

If the critical details of a visual task and also its background are entirely diffusely reflecting, brightness-contrast can be computed without actually measuring brightness, provided the diffuse reflection-factors are known. Some of these are presented in Chapter VI.

If the object has a lower diffuse reflection-factor (DRF) than that of its background, the brightness-contrast in percent is equal to

$$BC = 100 \times \frac{\text{DRF of background} - \text{DRF of object}}{\text{DRF of background}}$$

If the diffuse reflection-factor of the object is greater than that of its background, the brightness-contrast in percent is equal to

$$BC = 100 \times \frac{\text{DRF of object} - \text{DRF of background}}{\text{DRF of object}}$$

In Table VI are presented a few values of brightness-contrast as determined entirely by diffuse reflection-factors of objects and their backgrounds. It will be noted that for a background whose DRF equals 80 percent, the brightness-contrast diminishes rapidly as the DRF of the object increases beyond 30 percent. These lower brightness-contrasts may be visualized by thinking of light gray objects on white backgrounds. Low brightness-contrasts also result from socalled black objects on very dark gray backgrounds. These are not shown owing to the very low reflection-factors involved, although they are very common.

In the last column of Table VI are presented the brightness-contrasts of the same objects for a dark gray background whose DRF is 8 percent. It is worth comparing this column of values with the preceding one. Obviously, when the DRF of the object is 8 percent, the brightness-contrast is zero. If the DRF of the object differs only slightly from the value of 8 percent for the background, the resulting brightness-contrasts are low. This fact is emphasized when the DRF of the object is near or within the range of 7 to 9 percent.

TABLE VI

Brightness-Contrasts in Percent for Objects of Various Diffuse Reflection-Factors (DRF from 0 to 80 Percent) on Backgrounds of Two Diffuse Reflection-Factors, a Near-White with DRF = 80 Percent and a Dark Gray with DRF = 8 Percent. Values of Brightness-Contrast Are Approximate in Order to Eliminate Decimals.

DRF of Object Expressed in Percent	Brightness-Contrast in Percent — DRF of Background 80 percent	Brightness-Contrast in Percent — DRF of Background 8 percent
0	100	100
1	99	88
2	98	75
3	96	63
5	94	38
7	91	13
8	90	0
9	89	11
10	88	20
20	75	60
30	63	73
50	38	84
60	25	87
70	13	88
75	6	89
80	0	90

In completing the definition and computation of brightness-contrast, it should be pointed out that if the brightness or reflection-factor of the object is zero, the brightness-contrast is always 100 percent regardless of the background. Every object reflects some light, but the foregoing case is not a theoretical one. This condition is produced by silhouetting a black object against an illuminated background without permitting a measurable amount of light to fall on the object.

Examination of the simple formula for the computation of brightness-contrast also shows that if the brightness of the background is zero, the brightness-contrast is 100 percent. This condition is closely approached on a dark night outdoors where an illuminated object is seen amid almost complete darkness. It can be produced by placing a reflecting object before a hole in a deep box which is lined with black velvet. Now by illuminating the object with light which will not enter the hole in the box, the object will have any desired brightness, but the brightness of the background will be practically zero. Obviously the brightness-contrast will now be practically 100 percent for any brightness of the object.

The fact that the brightness-contrast is 100 percent when either the object or background is perfectly black or non-luminous is interesting but not of much practical importance excepting in fundamental research. It has been briefly discussed here in order to complete the picture of the very important but neglected factor —brightness-contrast.

BRIGHTNESS-CONTRAST AND THRESHOLD SIZE

At this point it is of interest to turn back to Fig. 26 in Chapter VII. That illustration shows the threshold size of a socalled "black" object (DRF = 3 percent) as viewed upon a series of backgrounds varying in diffuse reflection-factor from 3.4 percent to 80 percent, the latter being a socalled white background. In such a series it is obvious that the brightness-contrast between the object and background varies over a large range. Computing the extremes by means of the foregoing formula, we find the brightness-contrasts vary from nearly 12 percent to about 96 percent. If the reflection-factors were sufficiently extended at both ends of Fig. 26, the range of brightness-contrasts would be complete from 0 to 100 percent.

Throughout this range actually shown, the smallest size of the test-object which was barely visible under one footcandle of illumination varied from 4 minutes to 1.14 minutes. In actual physical size at a distance of 14 inches from the eye, this represents a range of about 16 to 4.5 thousandths of an inch. Under a level of illumination of 100 footcandles it is seen that the threshold sizes are generally little more than half their values under one footcandle.

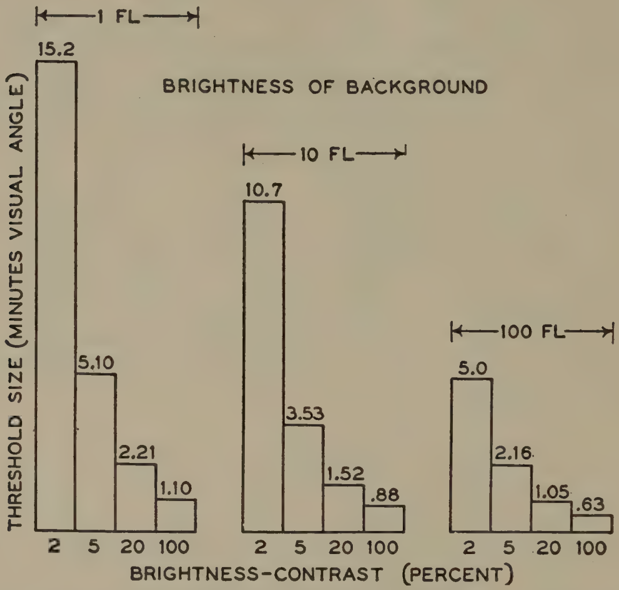


FIG. 29.—Brightness-contrast between the object and its background affects visibility very greatly as indicated by the minimum size of the object which is barely visible for four different brightness-contrasts. The effect of brightness-level is shown for three different brightnesses of the background—1, 10 and 100 footlamberts.

In Fig. 29 is shown the great influence of brightness-contrast on the minimum size of a perfectly black object that is barely visible for four different brightness-contrasts between the object and background. These values of threshold size are presented for three different levels of illumination—1, 10 and 100 footcandles. In the left-hand group it is seen that the threshold size varies from 1.1 to 15.2 minutes when the illumination is one footcandle. Obviously this is an enormous range of threshold size which emphasizes the great importance of brightness-contrast. This range is enormous from the viewpoint of visual acuity. Actually if an eyesight specialist found two persons who could barely see objects of 1 and 15 minutes, respectively, he would correctly conclude that one person had normal vision and the other was well along toward legal blindness. (See Chapters X and XI.) Let us again compare sewing with black thread on very dark material with reading very black print on white paper. The object to be barely visible in the former case must be many times larger than in the latter case. This is still true at the two higher levels of illumination—10 and 100 footcandles—as shown in Fig. 29. At the 100-footcandle level the object must be about eight times larger for the lowest brightness-contrast than for the highest.

Inasmuch as threshold size is a measure of visual acuity, the latter being proportional to the reciprocal of threshold size, it is obvious that brightness-contrast greatly influences visual acuity. The common test-charts, discussed in Chapter XI, are indeed limiting cases, and conclusions drawn from them can be, and often are, very misleading. If the eyesight specialist views such ranges in threshold size in terms of his test-charts and their ratings, he may be startled to learn how severe many visual tasks are and how inadequately seeing conditions have been considered or analyzed.

In Fig. 30 are presented the threshold sizes—the sizes of objects which are barely visible—for five different brightness-contrasts. For each contrast threshold sizes are presented for three levels of illumination—1, 10 and 100 footcandles. In the extreme left-hand group, the brightness-contrast of 2.5 percent represents a visual task involving black details or objects on a nearly black background. It is seen that the minimum sizes of barely visible objects—threshold sizes—are very large compared with those of the other groups to the right. Proceeding from left to right, each successive group represents a background of higher diffuse reflection-factor. That of the extreme right-hand group is a common white background with a DRF of 80 percent. In all cases, the test-object had a DRF of 3 percent.

In Fig. 31 the background in all cases is white, but the test-object varies from near-black (DRF = 3 percent) for the extreme right-hand group of high brightness-contrast to near-white (DRF = 78 percent) for the extreme left-hand group of low brightness-contrast. A visual task such as this page of printed matter is representative of the right-hand group. A visual task representative of the left-hand group might be the inspection of white cotton goods, in a textile mill, for flaws in the weaving which might be distinguishable by very slight differences in brightness.

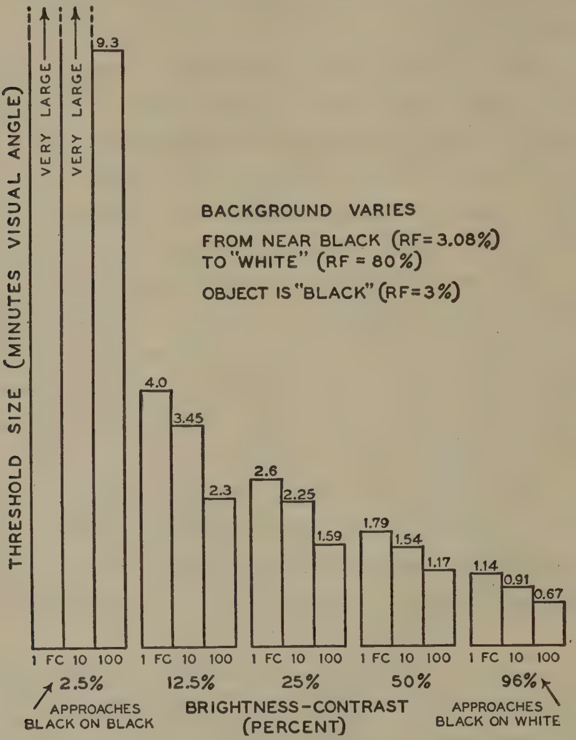


FIG. 30.—Showing the effect of level of illumination upon threshold-size of a "black" object for five different brightness-contrasts with its background. The left-hand group represents a black object on a very dark gray background. The extreme right-hand group represents a black object on a common white background.

It is interesting to compare Figs. 30 and 31. The corresponding values of threshold size in both right-hand groups are identical because the objects and their backgrounds are the same in both cases. For this reason the brightness-contrasts are also the same in the two right-hand groups. But there is a difference to be noted in proceeding to the left in each case. In Fig. 30 the DRF of the object remains constant but the background decreases

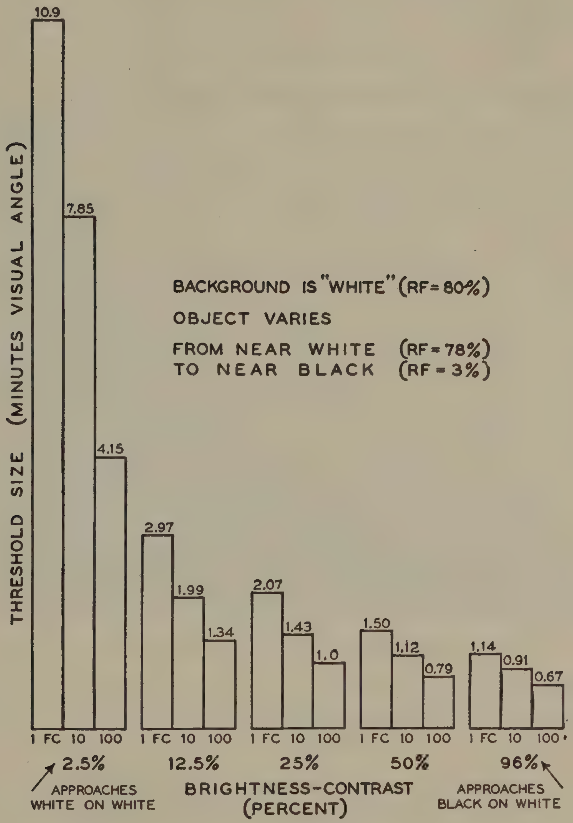


FIG. 31.—This represents the reverse of Fig. 30, for the object varies from "white" to "black" but the background is "white." The brightness of the background is always brighter for a given level of illumination than is the case in Fig. 30 excepting for the extreme right-hand group. This results in smaller threshold-sizes, respectively, than in Fig. 30.

in reflection-factor to a value only slightly less black than that of the socalled black test-object. In Fig. 31 the DRF of the background remains the same but the object decreases in reflection-factor as we proceed to the left until its brightness is only slightly less than white.

The difference in the threshhold values in the two illustrations is due to the differences in brightness-level of the background in the two cases, for the same level of illumination. For example, the brightness of the background for the left-hand group in Fig. 30 is much less than that of the corresponding group in Fig. 31, for the same level of illumination. This is true because in the former case the background is of much lower reflection-factor than in the latter case. The one is a socalled black and the other is a socalled white. Inasmuch as the object is very small compared with its background, the brightness-level from the viewpoint of seeing is, in effect, the brightness-level of the background.

Figs. 30 and 31 are worthy of a good deal of study, for they cover the range of most visual tasks and also a range of conditions from black on white to black on black, and also from black on white to white on white. As stated several times, one minute of visual size is subtended by an object or critical detail 4 thousandths of an inch in physical size at a distance of 14 inches. This relationship should be memorized in order to visualize, and to think in terms of, visual size in minutes.

BRIGHTNESS AND THE MAP OF SEEING

The influence of brightness is shown in Figs. 29 to 31 by comparing in each case the values of threshold size for the three levels of illumination—1, 10 and 100 footcandles. If the size of the critical details of a given visual task is fixed, and also the brightness-contrast, the only major remaining recourse for increasing visibility and making seeing easier is to provide more light properly applied. In the case of three-dimensional details, the direction of the light generally influences visibility very much, but this expedient is discussed later.

After directly viewing the relationships of the two fundamental factors—size and brightness-contrast—it should be of interest to study Fig. 32. Here the threshold combinations of size and contrast, for a brightness of the background of one footlambert, are plotted on the upper curve. This is the absolute borderline for normal vision and ideal laboratory conditions, between the world of invisibility and the world of visibility when the brightness-level is one footlambert. In this case the brightness is that of the socalled white background against which the objects are viewed. For each brightness-contrast there is a threshold size for an object in order for it to be barely visible under the specified conditions, including the specified brightness-level. Conversely, for each threshold size there is a threshold brightness-contrast for an object to be barely visible.

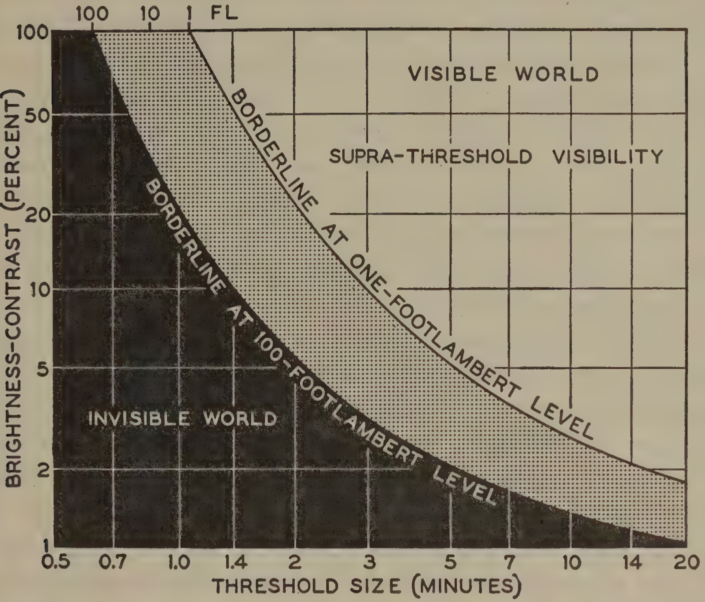


FIG. 32.—Showing how the "visible world" increases at the expense of the "invisible world" as the brightness-level increases. For a given case the brightness-level increases as the footcandle-level increases.

As the brightness-level is increased, it is seen in Fig. 32 that the world of visibility is increased at the expense of the world of invisibility. When the brightness-level is 100 footlamberts, the lower curve becomes the absolute borderline between visibility and invisibility of objects of various combinations of size and contrasts, for normal vision and ideal laboratory conditions. If the brightness-level is still further increased, the area of invisibility or "no seeing" decreases still further but finally the brightness factor has done all it can. The limitations are now those inherent to the visual sense. Thus it is seen that the map of seeing is greatly influenced by the level of illumination. Obviously, as the brightness-level decreases below one footlambert the invisible world grows larger at the expense of the world of clear seeing or supra-threshold visibility. Gradually the black area of Fig. 32 increases until it encompasses the entire area, for finally, in complete darkness—or blindness—nothing is visible.

In studying Fig. 32 it should be noted that the two brightness-levels are in footlamberts. These are footlambert-levels, not footcandle-levels. For a background which diffusely reflects only 10 percent of the light, for example, the 100-footlambert level is attained by an illumination level of 1000 footcandles. For a background which diffusely reflects only one percent of the incident light, the 100-footlambert level is attained by an illumination-level of 10,000 footcandles. These two footcandle-levels are common outdoors. One might reflect upon how easily one sees fine details outdoors in the daytime. Then the world of invisibility has shrunk to about its minimum size.

We might summarize for a range of 1 to 100 footlamberts as follows:

When the brightness-contrasts are low, the smallest detail that is barely visible varies from 5 to 20 minutes or from 0.02 to 0.08 inch at a viewing-distance of 14 inches.

When the brightness-contrasts are high, the smallest detail that is barely visible varies from 0.6 to 1.2 minutes or from about 0.002 to 0.005 inch at a viewing distance of 14 inches.

All these values, and all other fundamental data presented in these chapters, were obtained under the ideal conditions of laboratory control and environment, and, unless otherwise stated, by persons possessing normal vision. The subjects were engaged only in this task; they had no other responsibility; they could devote their entire attention and all their faculties to the task and there were no disturbing external influences. In addition, it should be noted that there was no consideration of how tedious and exacting the visual requirements were and no consideration given to the penalties of performing such threshold seeing for hours daily and day after day. In other words, there are no "factors of safety" in the values of threshold size in these illustrations or in any of the threshold data presented in other chapters.

Certainly in everyday seeing we need large factors of safety. We have them in bridges and buildings and on every hand. We have them in labor-saving devices and we should provide them for human seeing-machines. We have them in typography as represented by this page of printed matter. We have them in such a case because of the mass demands of readers—and because the strictly typographical factors, such as type-size, are controllable and obvious.

In everyday tasks of seeing the size of details, for example, may not be controllable. Backgrounds can often be used to increase brightness-contrasts, and more light and better lighting can always be called upon. What the factors of safety should be can scarcely be arrived at easily. They should be so large, if possible, that the visibility of any given task is equal to that of a suitable standard which guarantees safe, certain and easy seeing. Such considerations take us far above threshold or borderline seeing, into the realm of supra-threshold visibility. This is a concept and realm beyond the science of vision which deals largely with thresholds. Supra-threshold visibility is encompassed by the science of seeing and is the objective of specifications of light and lighting. This important realm is discussed in later chapters.

AN INTERESTING SUMMARY

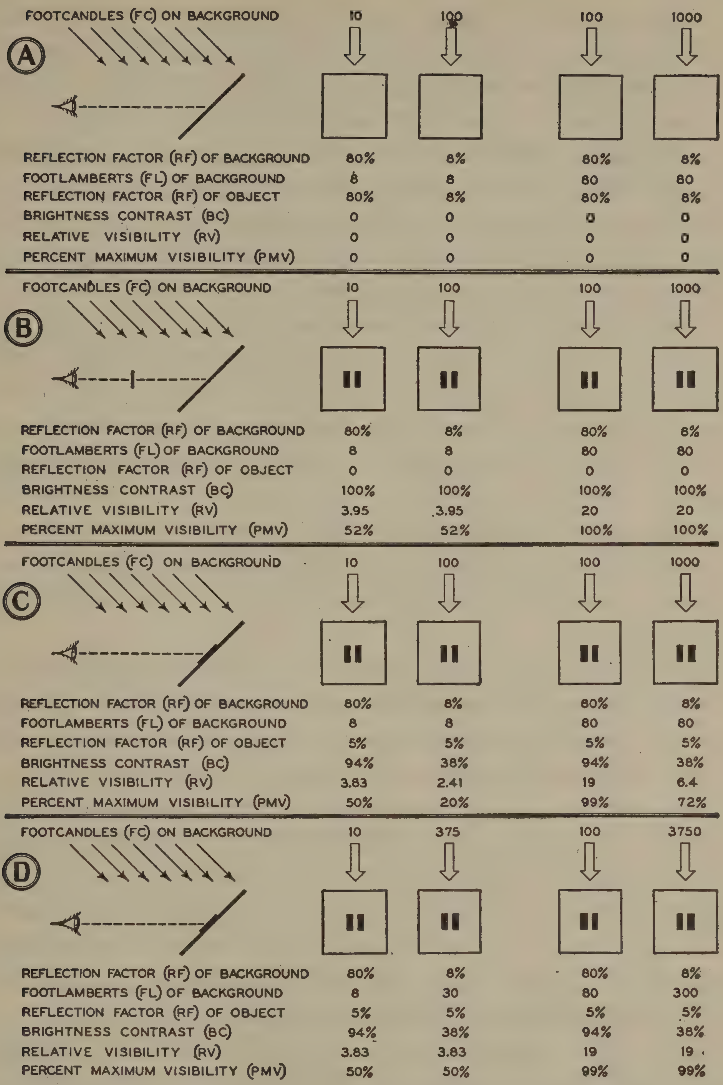
A summary of the results of various factors is presented in Fig. 33. This illustration contains data on visibility which, for the present, must be accepted at face value, if the reader is unacquainted with visibility measurements and the theory and practice of the Luckiesh-Moss Visibility Meter as discussed in later chapters.

For the present the reader should find Fig. 33 an interesting summary if some study be given to it. It will be noted that two pairs of footcandle-levels are used, 10 and 100 footcandles and 100 and 1000 footcandles. Each pair of footcandle-levels illuminates, respectively, two surfaces having diffuse reflection-factors of 80 and 8 percent. In each case are presented such pertinent facts as the diffuse reflection-factors and the brightnesses of object and background, the resulting brightness-contrast which is entirely a matter of diffuse reflection-factors of object and background, the relative visibilities and the percent of maximum visibility.

In the group designated by *A* the object has the same diffuse reflection-factor as the background and, therefore, is invisible.

In group *B* the object is silhouetted against the background and, receiving no light, its brightness is zero. As a result, the brightness-contrast is 100 percent in each case. It is seen that 10 footcandles on one background (white) produce the same visibility as is produced by 100 footcandles on the other background (dark gray), which reflects only one-tenth as much light as the white background. For the right-hand pair, 100 and 1000 footcandles, respectively, produce equal but higher visibilities. According to our visibility scales, the visibility for the right-hand pair of group *B* is a maximum. However, the reader need not be concerned with the meaning of the visibility values for the present.

In group *C* the "black" object is on the background and receives the same amount of light as the background. Inasmuch as the diffuse reflection-factor of the object is 5 percent, the brightness-contrast is 94 percent for the "white" background and only 38 percent for the dark gray background. Actually the relative visibilities in the two cases are considerably different, as indicated by the two values.



FOOTCANDLES (FC) ON BACKGROUND	10	100	100	1000
REFLECTION FACTOR (RF) OF BACKGROUND	80%	8%	80%	8%
FOOTLAMBERTS (FL) OF BACKGROUND	8	8	80	80
REFLECTION FACTOR (RF) OF OBJECT	80%	8%	80%	8%
BRIGHTNESS CONTRAST (BC)	0	0	0	0
RELATIVE VISIBILITY (RV)	0	0	0	0
PERCENT MAXIMUM VISIBILITY (PMV)	0	0	0	0

FOOTCANDLES (FC) ON BACKGROUND	10	100	100	1000
REFLECTION FACTOR (RF) OF BACKGROUND	80%	8%	80%	8%
FOOTLAMBERTS (FL) OF BACKGROUND	8	8	80	80
REFLECTION FACTOR (RF) OF OBJECT	0	0	0	0
BRIGHTNESS CONTRAST (BC)	100%	100%	100%	100%
RELATIVE VISIBILITY (RV)	3.95	3.95	20	20
PERCENT MAXIMUM VISIBILITY (PMV)	52%	52%	100%	100%

FOOTCANDLES (FC) ON BACKGROUND	10	100	100	1000
REFLECTION FACTOR (RF) OF BACKGROUND	80%	8%	80%	8%
FOOTLAMBERTS (FL) OF BACKGROUND	8	8	80	80
REFLECTION FACTOR (RF) OF OBJECT	5%	5%	5%	5%
BRIGHTNESS CONTRAST (BC)	94%	38%	94%	38%
RELATIVE VISIBILITY (RV)	3.83	2.41	19	6.4
PERCENT MAXIMUM VISIBILITY (PMV)	50%	20%	99%	72%

FOOTCANDLES (FC) ON BACKGROUND	10	375	100	3750
REFLECTION FACTOR (RF) OF BACKGROUND	80%	8%	80%	8%
FOOTLAMBERTS (FL) OF BACKGROUND	8	30	80	300
REFLECTION FACTOR (RF) OF OBJECT	5%	5%	5%	5%
BRIGHTNESS CONTRAST (BC)	94%	38%	94%	38%
RELATIVE VISIBILITY (RV)	3.83	3.83	19	19
PERCENT MAXIMUM VISIBILITY (PMV)	50%	50%	99%	99%

FIG. 33.—Showing the relationships of the reflection-factor and illumination of the background upon the brightness of the background and upon the brightness-contrast between the object and its background. The effect of all these upon the visibility of the object is also shown. (See Chapter XII.)

In group *D* it is seen how this difference in visibilities is overcome; that is, how much more light is necessary to counteract the effect of lower brightness-contrast. Actually it requires 375 footcandles for the object on the dark gray background to have the same visibility as the object on the white background when the latter is illuminated to a level of only 10 footcandles. With the right-hand pair it will be noted that 100 and 3750 footcandles are necessary to make the relative visibility equal in the two cases and practically a maximum.

These facts are above controversy for they are the results of considerations of brightness and of brightness-contrast. Furthermore, they can be checked by suitable measurements by anyone. They illustrate strikingly the effects upon threshold size and visibility of the combination of diffuse reflection-factor, brightness and brightness-contrasts. These facts are axiomatic. The illumination-level is extended from 10 footcandles in the one case to 375 footcandles in the other case in order to have the same threshold size or visibility for the same object on two different backgrounds.

It is interesting in this connection to follow the same reasoning through the various groups of Fig. 33, for the right-hand pair, the 100 and 1000 footcandle-levels. It should be noted that the visual task involved is a relatively easy one for the object is black or near-black and the background is socalled white in one case and dark gray in the other. If the reflection-factors of the backgrounds had been lower, the footcandle-levels would have to be higher. Finally one might consider ease of seeing. This page can be read with greater ease under 100 footcandles than under 10 footcandles. From this viewpoint the right-hand pair of footcandle-levels is also of interest.

The 3750 footcandles on a background whose reflection-factor is 8 percent produce a brightness of only 300 footlamberts. This is about the average brightness of a green grass lawn outdoors in the daytime. Considerations such as these have led the author for many years to discuss levels of illumination of 100 footcandles and even hundreds and thousands of footcandles for many tasks of critical seeing. When someone states categorically that 10 or 20 footcandles are enough for seeing, he reveals his gross ignorance of the various factors upon which visibility and ease of seeing depend. It is also obvious in such cases that the shortcomings or fallacies of footcandles are not appreciated.

It is now adequately proved, from several approaches, that the brightness-levels of many common areas outdoors in the daytime are necessary for reasonably high visibility of many visual tasks and are ideal from the viewpoint of ease of seeing. How rapidly lighting practice moves toward those ideals depends upon various practical considerations. However, great strides would be immediately made if lighting or seeing specialists and those who perform critical tasks of seeing for long periods fully grasped the knowledge now available.

CONTRAST-SENSITIVITY

The ability to distinguish small details is termed, visual acuity. Similarly, the ability to distinguish differences in brightness is termed, contrast-sensitivity. This visual function is readily studied by ascertaining the smallest difference in brightness that a person can see under a given set of conditions. If the minimum brightness-difference that one person can see is 5 percent but is 10 percent for another person, under identical conditions, the contrast-sensitivity of the former person is twice that of the latter. An analogy is provided by time and speed. If one person can run a given distance in 10 seconds and another person runs it in 20 seconds, the speed of the former person is twice that of the latter.

At ordinary brightness-levels in the daytime most persons can readily distinguish the difference in brightness between two adjacent surfaces if this difference is as small as one or two percent. However, accurate measurements reveal considerable variation in contrast-sensitivity among persons having socalled normal vision. The fact is that the eyesight specialist seldom measures contrast-sensitivity. His interest is almost universally confined to visual acuity.

As the brightness decreases from daytime levels, the minimum perceptible brightness-difference increases and variations among individuals become more obvious. At a brightness-level of 0.01 footlambert, some persons can barely distinguish a difference in brightness of 15 percent while other persons can barely distinguish a brightness-difference of 30 percent. Obviously the latter persons are literally blind to brightness-differences that the former persons can see. This is a very important factor in seeing at low brightness-levels.[18] A brightness-level of 0.01 footlambert is common on the highway at night and is generally much higher than the brightness-levels due to moonlight. Therefore, it should be obvious that the variation in contrast-sensitivity among individuals is of great importance at low brightness-levels and particularly outdoors at night on highways and elsewhere. Actually under those conditions we must rely largely upon brightness-difference to see objects and contrast-sensitivity becomes an important visual function. Life or death may depend upon an individual's sensitivity to brightness-difference.

As the brightness-levels decrease still further to those on starlit nights and beyond, the minimum perceptible brightness-difference increases until eventually it reaches 100 percent. In other words, at lower and lower levels of brightness, the difference in brightness between two adjacent surfaces must be larger and larger if an observer is to see the difference.

Contrast sensitivity is always of some importance, but it has very great significance at low brightness-levels. Lookouts on ships, night drivers, night flyers and others should be tested for this function. For this purpose the Luckiesh-Moss Low-Contrast Test-Chart was developed a number of years ago.[18]

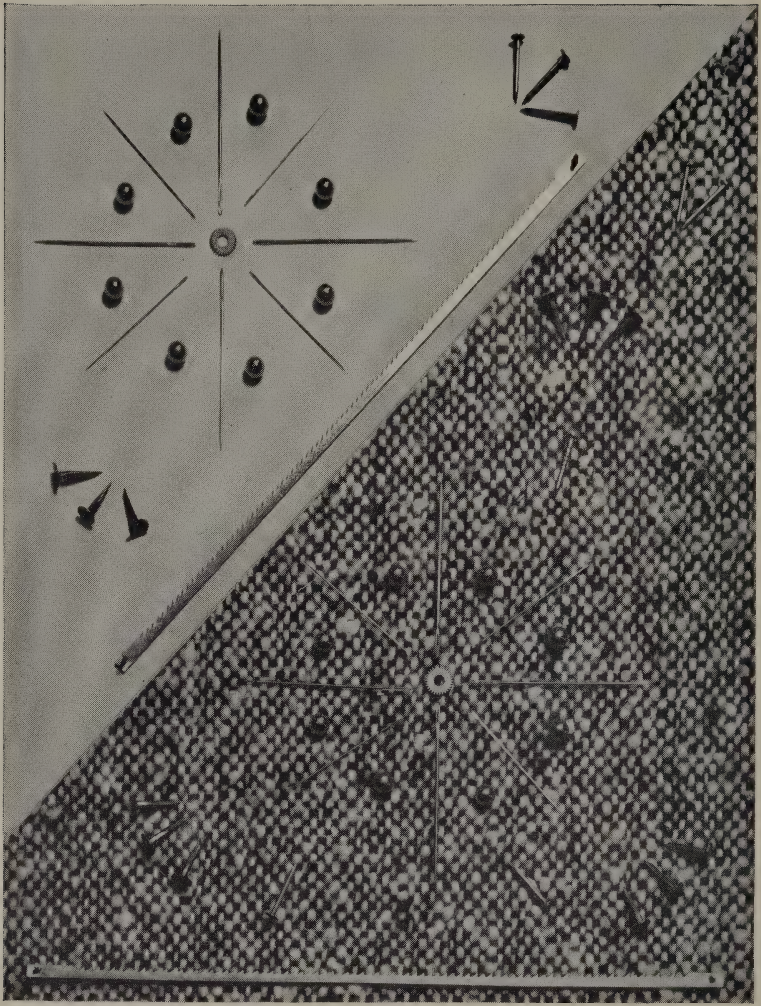


Plate IX.—The objects on the plain background are seen almost instantly. Obviously it takes time to see those on the patterned background. Here, brightness and brightness-contrast are far from adequate and the pattern also tends further to reduce the visibility of the objects.

CHAPTER IX

It Takes Time to See

Among the complications of seeing is the fact that it is not instantaneous. The time factor is always present. Therefore, it is included among the four fundamental factors—size, brightness, brightness-contrast and time. In preceding chapters which have dealt in some detail with the first three of these four factors, time has been eliminated from the discussion. Actually, it was present in all the fundamental researches which yielded the data pertaining to the relationships of the three factors. However, it was present as a constant controlled factor.[19]

There are various viewpoints from which the factor of time can be considered. It is present as one reads these lines of print. It is present in every continuous process of seeing in the performance of countless tasks of seeing. When conditions are such that the details of a visual task are of high visibility, one not only sees more easily but more quickly.[20] However, the time factor may be easily overrated in continuous tasks, such as reading, in which one has gained proficiency. In the continued practice of reading, one also develops natural or rhythmic rates. As a result, one's rate of reading, for example, is not increased in proportion to increases in visibility.[1] However, speed of reading, or speed of performance of any seeing task of a continuous nature, is increased within certain limits by increasing the level of illumination or by increasing visibility and ease of seeing by any other means.

Many tasks of seeing are not of the continuous type exemplified by reading this printed page. They are more or less discontinuous. For example, a workman at a bench or a person doing office work may be engaged in seeing of an intermittent variety. The performance of useful work involves seeing this and that. If visibility is low for reasons inherent in the task itself, or for lack of a suitable background, proper direction of light or amount of light, the human seeing-machine is held up momentarily here and there.

Lost motion and lost time add up to less useful work accomplished. On every hand one can witness this waste due to poor seeing conditions, and there is added to this the waste of energy and the waste due to annoyance and fatigue. All this adds up to waste of time, effort and human resources.

The time factor is obviously important where split-second seeing is necessary as in inspection, in machine work, in safety and in countless aspects of daily activities. Seeing is a small common word that has overwhelming significance in almost every human activity. The factor of time, being intimately involved in seeing, is a perpetual influence in human efficiency, production, safety and welfare.

EYE-MOVEMENTS AND TIME-INTERVALS

We do not see while our eyes are in motion. For example, in reading this line of print, the lines of sight of the two eyes converge upon this line and this point of fixation proceeds in a series of jumps along each line. Depending upon our individual characteristics, our eyes fixate—come to a dead stop—several times along each line. The number of stops per line varies somewhat for educated adult readers and the character of the reading material.[1] It commonly averages about six times per line of ordinary length such as those on this page. In other words, we read a line in a manner analogous to drinking water; that is, by successive swallows. It is only during the stops that we actually see the words and we read a portion of this line of print during each brief fixational pause.

Careful studies of the stopping time of the eye show that the average minimum length of each pause is about 0.07 second under ideal laboratory conditions.[21] A fair average of the longest pauses is about 0.3 second when only the discrimination of a simple object is involved. Therefore, these are limiting periods of time fundamentally involved in seeing. Generally, in performing more complicated tasks of seeing under usual conditions, these pauses are necessarily greater. In addition to these there are reaction-times. These are the periods of time which elapse between seeing and acting. As a consequence the time required to see or to recognize an object may be only a few tenths of a second, but the total interval, including the time necessary to act, is still greater. Therefore, we may view any task involving seeing as a complex series of minute time-intervals.

It is possible to study the eye-movements and the time-intervals involved by means of the electrical changes which occur in the eye-muscles.[1] These electrical changes are very minute, for many of them are only fractions of a millionth of a volt. Furthermore, they occur in small fractions of a second. However, by resorting to modern methods of amplification as utilized in radio receiving sets, these minute electrical changes in the eye-muscles due to eye-movements can be magnified many million times. As a consequence, we can obtain such records as illustrated in Fig. 34.

In this case the record was made while an educated adult subject was reading under constant controlled seeing conditions. Fig. 34 is only a small portion of a continuous graphic record and represents the facts obtained from reading two successive lines of print such as those on this page. Although this is a graph of very minute voltage changes, it reveals much of the process of reading which is in reality a discontinuous process consisting of a series of eye-movements and fixational pauses. This particular portion of the record was chosen because it includes the typical disturbance of a blink and also a "regression." This latter means an over-shooting of the point of fixation which necessitated a backward movement. Eye-movements toward the left result in upward sweeps of the graph and those toward the right result in downward sweeps.

We need not go deeply into the details of Fig. 34 beyond the major facts indicated. Some of the time-intervals have been included and other facts are of some interest. It will be noted that the movement of the eyes backward from the end of one line to the beginning of the next was accomplished in 0.12 second. Actually, the point of fixation, or convergence of the eyes upon the line of print, traveled at the rate of 140 feet per minute in this backward sweep. Then the eyes paused successively about six times, or took about six steps in the process of reading the first line.

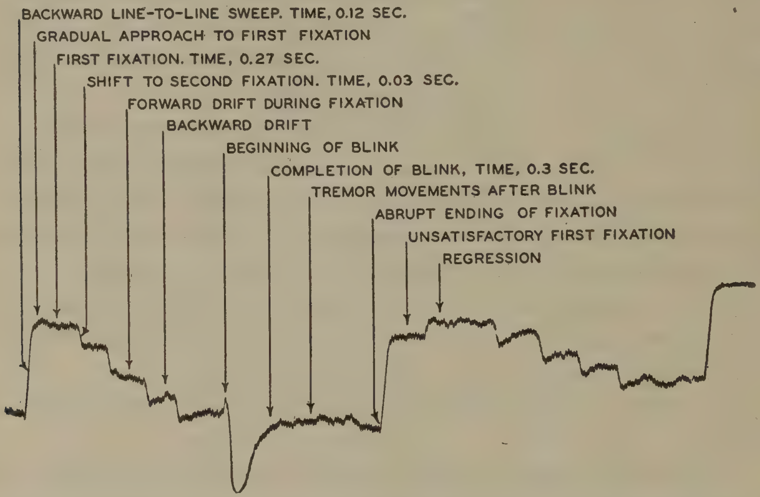


FIG. 34.—An electromyogram of the "action currents" in certain extrinsic eye-muscles while reading two successive lines of print such as those on this page. In order to make this record the minute electrical changes must be amplified millions of times.

The time-interval of these jumps between pauses is of the order of 0.03 second. The backward sweep from the end of the first line to the beginning of the next is shown in the middle of the graph. Apparently the second jump or pause in reading the second line was unsatisfactory, for it was corrected by a slight backward movement, termed a regression. Then the eyes continued the series of pauses, a total of about six, in reading the second line. All these events in the reading of two lines of print took place in less than five seconds, for this particular subject read about 23 lines of print per minute or at the rate of about 2 lines in 5 seconds. The length of the lines of print was about the same as those on this page.

Eye-movements are introduced in this discussion merely to give the reader an idea of the many small time-intervals involved in seeing even in a commonplace task such as reading. Fig. 34 also aids in revealing how entwined the time factor is and should give an idea of the difficulty of separating it from all the other factors. In reading for a period of eight hours, the eyes "stop" and "go" about 70,000 times and their point of fixation or convergence travels carefully and critically along each line of print for a total distance of about 3700 feet. Even a casual consideration of these facts reveals the severity of prolonged tasks of critical seeing. They emphasize the slavery of near-vision to which civilization has relegated human eyes and human seeing-machines.

Incidentally, the aid which brightness brings to the reader is also illustrated by a series of records, similar to Fig. 34, made before and after reading for an hour under one and 100 footcandles, respectively.[37] In Table VII is a summary made from several hundred records similar to that illustrated in Fig. 34. The subjects were educated adult readers and the reading matter was of excellent printing and the typography consisted of 11-point type with two points of leading. The effects of fatigue are ob-

TABLE VII

Effects of an Hour's Reading Under Two Levels of Illumination—1 and 100 Footcandles, Respectively. The Reading Matter, Printed with 11-Point Type with 2 Points of Leading, Was Far Above the Average Typography Commonly Encountered.

	Level of Illumination	
	1 FC	100 FC
Percent increase in average		
Reading-time per line	18	4
Fixational pauses per line	5	3
Duration of fixational pauses	14	0
Regressions	36	32

viously greater for the one-footcandle level as is evidenced by a greater increase in reading time and in the number and duration of the fixational pauses. These effects would have been even greater if the reading matter had been printed with smaller type. However, the large type and excellent typography were chosen in order to ascertain what effects could be largely attributable to level of brightness or illumination. It is seen that, even for this relatively easy task, there is a marked advantage to higher levels of illumination.

CERTAINTY OF SEEING

With the foregoing glimpses of how the time is intimately and complexly involved in seeing, let us discuss briefly some fundamental time-intervals. That it takes time to see can be made rather obvious in many ways. However, there is the important aspect of certainty of seeing. Efficiency, production, accuracy and safety depend upon certainty of seeing.

If, under controlled conditions, a given test-object is exposed to view for measured short periods of time, one may ascertain the minimum period of time necessary to recognize the object every time it is exposed to view. This is the minimum time-interval for 100-percent certainty of seeing. As this time-interval is decreased further, the subject is no longer able to recognize the test-object every time it is exposed to his view. As the period of exposure of the test-object is further decreased, the subject eventually recognizes the object only 50 percent of the times that it is exposed to view. Obviously he could do as well by guessing, with his eyes closed. This is zero-percent certainty, the threshold between equal certainty and uncertainty. The fact that a subject does not recognize the object every time it is presented emphasizes the fact that he is a *human* seeing-machine. The focus of the eyes and of the attention varies for human machines. Seeing is a human activity consisting of variables not inherent in inanimate machines or measuring devices.

In Fig. 35 are shown the results obtained with our parallel-bar test-object, when consisting of black bars of a given size on a white background. The position of the parallel bars was altered to horizontal, vertical or diagonal in successive exposures and was unknown to the subject who had to recognize it in addition to distinguishing the two bars. It is seen that the period of time necessary for 100-percent certainty of seeing is about twice that for zero certainty. The gray portion of each block represents the increase in the time necessary to increase certainty of seeing from barely zero to barely 100 percent.

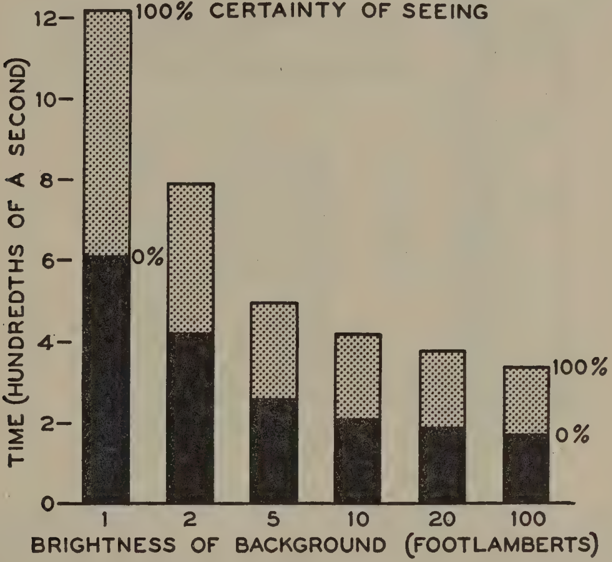


FIG. 35.—Showing the time required to recognize a black object on a white background with 100-percent certainty—every time it is presented—and with zero certainty—half the times that it is presented to view. The average minimum time required to recognize the object decreases markedly as the brightness-level or footcandle-level increases.

It is also evident that the time required for any degree of certainty of seeing of this particular black object on a white background is greatly influenced by the level of brightness or illumination of the background. In this case, the results are given for a theoretically perfect white background so that the relation between footlamberts and footcandles is simplified. In fact, the footlambert scale is also a footcandle scale. When this same black object is viewed against a dark gray background which reflects only one-tenth as much light as the white background, the footcandle values in Fig. 35 must be increased ten-fold.

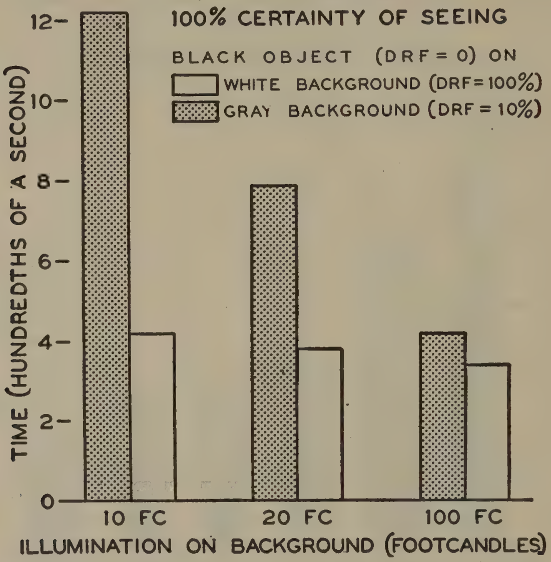


FIG. 36.—The minimum time required to recognize an object is greater for a gray background than for a white background at the same level of illumination. Obviously in the former case the brightness-contrast between the object and its background is less than in the case of the white background. Also the brightness of the gray background is only one-tenth that of the perfectly white background for a given level of illumination.

The effect of the brightness of the background, against which the black test-object is viewed, is also shown in Fig. 36 for the condition of 100-percent certainty of seeing. The minimum time required for recognition of the object with 100-percent certainty is shown for the white and gray backgrounds under three levels of illumination—10, 20 and 100 footcandles. One background is theoretically a perfect white whose DRF equals 100 percent and the other is a gray whose DRF equals 10 percent. The results shown in Figs. 35 and 36 emphasize again the importance and definiteness of brightness-levels compared with footcandle-levels.

Obviously they also reveal the powerful influence of brightness-contrast between object and background.

TIME AND THRESHOLD SIZE

In ascertaining the minimum period of time that the eyes can fixate upon an object, it was found, as previously stated, that the range was generally from 0.075 to 0.3 second. In other words, the longest pauses averaged about four times as great as the average of the shortest pauses. With these as a basis, our standard test-object of various sizes and contrasts with its background was exposed systematically to a representative group of subjects with normal vision for periods of 0.075 and 0.30 second, respectively.

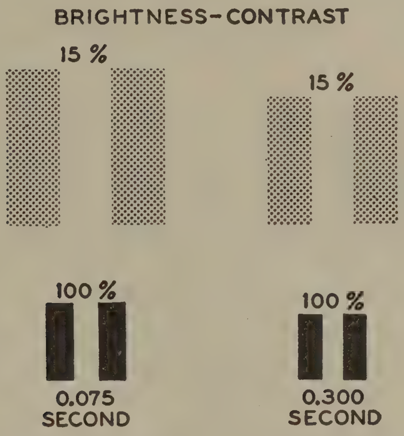


FIG. 37.—Illustrating the relative sizes of our parallel-bar test-object to be barely recognizable under the same level of illumination for two different times of exposure—0.075 second and 0.300 second. In one case the test-object was gray on a white background and in the other it was black on a white background.

The results are shown in Fig. 37 for a black object having a 100-percent contrast with its white background and a gray object having a 15-percent contrast with its white background. It is seen that, within the range of exposure-time, the minimum size of the black object to be barely visible under 100 footcandles of illumination varied about 20 percent. The threshold size of the gray object was about twice as large as that of the black object and its size also varied about 20 percent for the range of exposure time. This does not appear to be a large range but it should be emphasized that these results were obtained under ideal controlled laboratory conditions for which the range should be less than under usual conditions of seeing. Incidentally, Fig. 37 illustrates in still another way that the brightness-contrast between the object and its background can be considered the most important factor, fundamentally and practically, in everyday seeing. Still, it is the most neglected.

SPEED OF SEEING

Speed is the reciprocal of time. For example, if under one condition an object can be recognized in one-half the time necessary under another condition, the speed of seeing in the former case is twice that in the latter case. Although time is a fundamental factor intimately entwined with the other three fundamental factors—size, brightness and brightness-contrast—it is also much more than this in everyday seeing. The time required to perform a task, such as reading, involves human factors such as education, skill and alertness. Many other tasks involve motions and, therefore, such additional human factors as dexterity, mental agility and reaction time play a part. For these reasons it is extremely difficult to generalize from results of most tests. Therefore, in a brief survey of time and speed in seeing, only some glimpses of various avenues are presented.

As already stated, proficient readers, for example, develop a natural or rhythmic rate. It takes a good deal to affect this rate. Furthermore, one's natural rate of reading or working is not a maximum rate. Therefore, in effect, a reserve is available to compensate for less favorable seeing conditions. One could read these printed lines nearly as rapidly under a few footcandles of illumination as under 100 footcandles—but by no means as easily. In other words, one has a reserve in the matter of speed which is drawn upon to compensate largely for smaller type, poorer printing and lower levels of illumination. Within fairly wide limits the speed of reading may not differ greatly. Therefore, speed of performance is inherently an insensitive measure of ease of seeing and often too much importance has been attached to it as a criterion of seeing conditions.

For these and other reasons, it is often necessary to compare two rather extreme conditions in order to obtain a marked difference in rate of performance. For a long time these facts, which should be obvious, have obscured the real issues. For example, the rate of reading this page of printed matter by educated adults possessing normal vision may be only about 25 percent less under one-tenth of a footcandle than it is under 10 footcandles. It is only a few percent higher under 100 footcandles than under 10 footcandles. However, if subjects read for long periods under two different levels of illumination, the natural rate of reading being less than the maximum possible rate, there is a reserve available. This is analogous to a runner who has a fair sprint left at the end of a long run, provided he has not reached the point of exhaustion. Tests of rate of reading or of the performance of any visual tasks are of little practical value if they involve such extremes.

The effect of brightness-contrast between the printed matter and its background upon speed of reading is illustrated by the results obtained for the same reading matter printed on white paper and gray paper, respectively. The diffuse reflection-factor of the white paper was 80 percent and that of the gray paper was 23 percent. The speed of reading was much less for the gray paper. Furthermore, when the level of illumination was increased from 4 to 20 footcandles, the rate of reading increased nearly 60 percent in the case of the gray paper and 17 percent in the case of the white paper. In this case Old English type was used in order to make the task of reading more difficult.

We have devised various tests for revealing the effect of seeing conditions upon speed of seeing. All of them are subject to the difficulties mentioned. However, one of these tests, the Luckiesh-Moss Demonstration Visual Test, is one of the most successful because it minimizes human factors as much as possible.[22] In Fig. 38 are presented the average results obtained under different levels of illumination by a group of subjects possessing normal or near-normal vision. The time required to perform this test is seen to vary from about 70 seconds under 3 footcandles to 40 seconds under 50 footcandles.

Notwithstanding the inherent difficulties involved in revealing the time factor, it is seen that it is important. Furthermore, if appropriate tests are made with proper controls it is seen that speed of seeing is measurably influenced by seeing conditions. Many investigations reveal that more light, better lighting and other improvements in seeing conditions definitely increase the useful work done.[7] However, in devising such tests it is well to bear in mind the difficulties involved in seeing tasks in which natural or rhythmic rates are acquired along with proficiency.

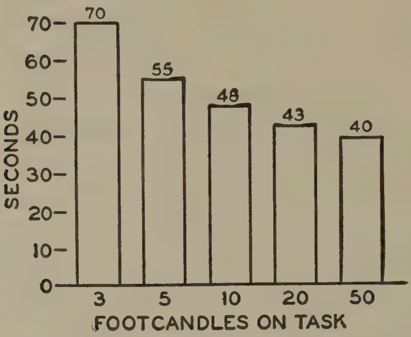


FIG. 38.—Showing how the time required to perform a special visual task—the Luckiesh-Moss Demonstration Visual Test—decreases as the level of illumination increases.

RESIDUAL AFTERIMAGES

All of us are familiar with the afterimages which linger for some time after we have looked at a bright light-source or other bright area. We need not be reminded that they affect our ability to see or that it takes time for them to disappear. They are constant reminders of the blinding effect of glare and of the annoyance and inefficiency in seeing which they cause. In many cases they are the direct cause of accident. These afterimages are obvious but there are others which are discoverable only by careful studies of the time required for seeing. In reading these lines, afterimages linger at the retina and, to some slight extent at least, all along the line, including the mind.

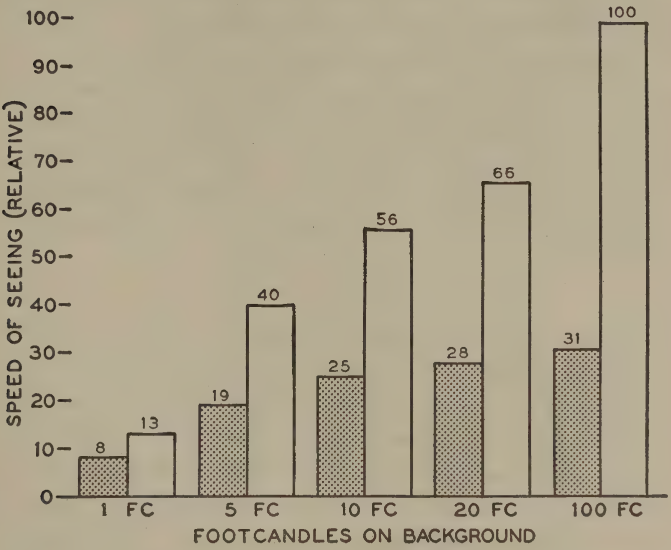


FIG. 39.—Speed of seeing is the reciprocal of the time required for seeing. The speed of seeing is markedly less (shaded blocks) when the object to be seen is presented to view immediately after viewing another object. The latter leaves an image on the retina momentarily which is in effect a "confusion pattern." The white blocks indicate a much greater speed of seeing (less time required for seeing) when the object to be seen rises out of a plain white field.

In determining the threshold relationships of the fundamental factors, which are presented in many illustrations in these chapters, the test-object is generally preceded by a patternless field of the same brightness as the background of the test-object. This is true in all cases, unless otherwise obvious, in which the object is presented to view for a controlled measured interval of time. However, it is of interest to expose the eyes first to a given pattern immediately before exposing the test-object to view—and immediately after if one wishes.

Typical results of such a seeing condition are shown in Fig. 39. In one case, indicated by the shaded blocks, the presentation of the object to view for a measured time-interval was immediately preceded and followed by the presentation of a field consisting of broad white and black diagonal stripes. In the other case, indicated by the plain blocks, the test-object was preceded and followed by a plain white field. It is seen that the speed of seeing was much greater when there were no "after-images" of a pattern lingering on the retina or anywhere along the line to and including the mind. The effect of increasing level of illumination is far more marked in one case than in the other. This fact is of practical importance in intimate considerations of seeing although in many cases nothing can be done about it.

DEFECTIVE VISION

The time required to see or to recognize a given object under specific seeing conditions is generally greater for persons with defective eyesight than for those possessing normal vision. Therefore, speed of seeing depends upon the status of vision in any given case. Inasmuch as vision is a variable over the entire range from normal to blindness, it is out of the question to present data covering all degrees and kinds of eye-defects. For example, the time required to recognize our standard test-object was two to three times greater for a subject with moderate astigmatism than for a group of subjects with normal vision.

Obviously as vision becomes more and more subnormal, the time required for seeing continues to increase. Speed of seeing correspondingly decreases until it eventually approaches and finally becomes zero. Here again, improvement in visibility by any means generally aids those with subnormal vision even more than those with normal vision. In this connection it should be emphasized that average vision is subnormal and many persons included in the grand average have vision far below the average. These and many other considerations emphasize the need for large factors of safety in seeing. This is particularly true in split-second seeing upon which safety of life and limb depends.

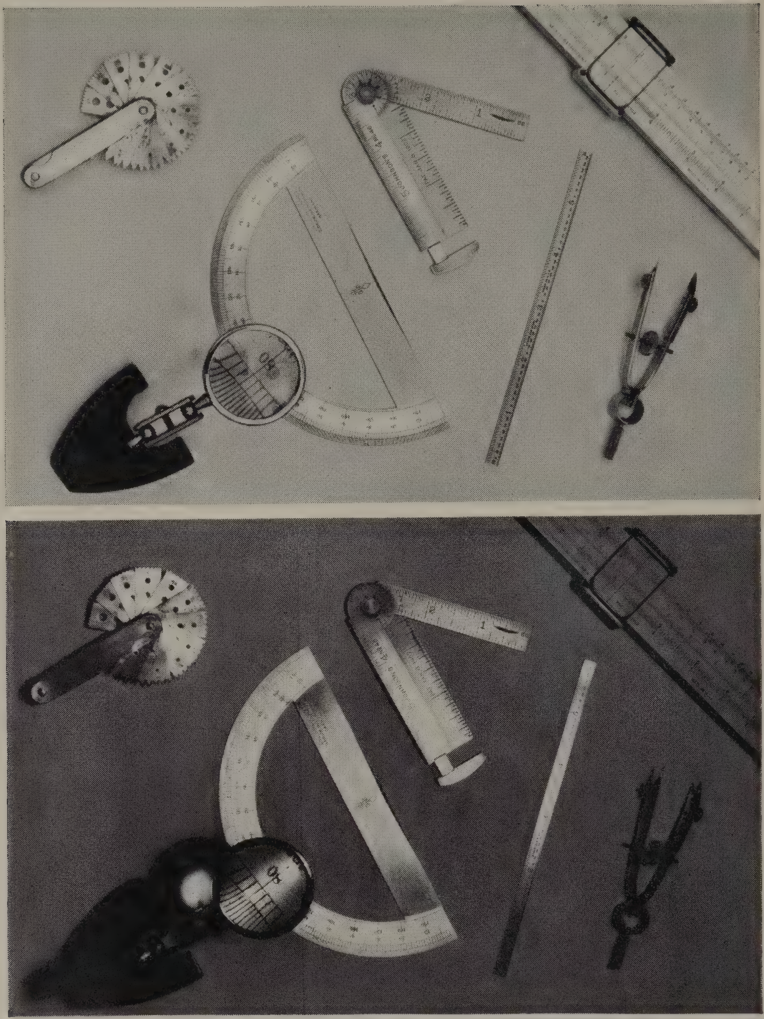


Plate X.—Visual acuity is not merely a characteristic of the visual sense. It also depends upon all factors, such as brightness, brightness-contrast, level of illumination and specular reflection, which influence the visibility of the objects. For objects of low brightness-contrast with their background, visual acuity increases markedly up to levels of hundreds—even thousands—of footcandles. Specular reflection is not conspicuous under diffuse illumination (above) but by adding supplementary lighting (below) it can be utilized or avoided as desired.

CHAPTER X

Visual Acuity

Visual acuity is commonly defined as the ability to distinguish fine details. Just as speed increases in proportion to decreases in time required to perform a task, visual acuity increases in proportion to decreases in threshold size or minimum size which is barely visible. If, for example, the minimum sizes necessary for objects to be seen are 1, 2 and 4 minutes, respectively, the visual acuities are relatively 100, 50 and 25. This is true regardless of the reasons for the different threshold sizes necessary for barely recognizing the respective objects. There are several major reasons why visual acuity is high or low as the case may be, such as different degrees of eye-defectiveness, different levels of brightness or illumination, and different brightness-contrasts between object and background.

It has become the custom for eyesight specialists to associate visual acuity entirely, or at least overwhelmingly, with eyesight. Furthermore, they commonly utilize test-charts consisting of black letters or other characters on a white background. These visual tests or tasks are highly special cases of nearly 100 percent brightness-contrast. Among all the countless visual tasks in which backgrounds are not white and critical details are not black, the brightness-contrasts vary from 0 to 100 percent.

REFLECTION-FACTOR OF BACKGROUND

A simple example of the necessity for a broader viewpoint, in dealing with everyday seeing than in dealing merely with the visual sense, is presented in Fig. 40. The results are the averages obtained by a representative group of adult subjects *possessing normal vision.* Our standard test-object was black and it was viewed against white and gray backgrounds, respectively. The diffuse reflection-factors and brightness-contrasts for the two cases are indicated. In each case three levels of illumination were used. Obviously, the differences in visual acuity are not due to differences in eyesight, for all the subjects had normal vision. In fact, the average visual acuity of all the subjects is expressed as 100 for the black-on-white test-object under a level of illumination of 10 footcandles.

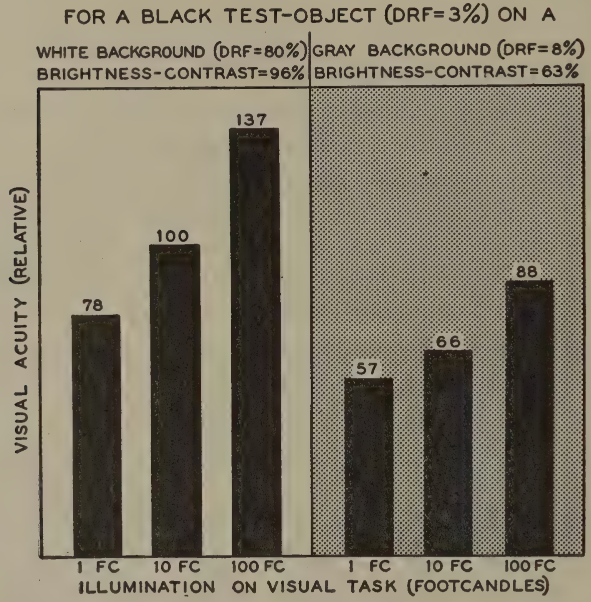


FIG. 40.—Visual acuity is proportional to the reciprocal of threshold-size. The greater the minimum size necessary for the object to be barely visible, the lower visual acuity is—for any reason. Visual acuity is markedly less for a black object upon a gray background than upon a white background for any given level of illumination. In both cases visual acuity increases markedly with increase in footcandles upon the background.

It is an interesting fact that visual acuity is far different for the two cases under the same level of illumination. Visual acuity also increases markedly as the level of illumination increases. For example, visual acuity for the black object on a white background is 37, 51 and 56 percent greater for the three levels of illumination—1, 10 and 100 footcandles, respectively—than for the black object on the gray background.

For those individuals who have to perform tasks of low brightness-contrast, exemplified by the black objects and gray background, their visual acuity is, in effect, only 66 percent, if the 10-footcandle level is used as a basis. This is just as true, practically, as if their visual acuity were actually found to be only 66 percent by the usual black-on-white test-charts. Of course, when relieved from their low-contrast tasks, they enjoy socalled normal eyesight.

In Fig. 41 the results are presented for black objects on a series of backgrounds with diffuse reflection-factors ranging from 3.4 percent to 80 percent, and for three levels of illumination—1, 10 and 100 footcandles. It is seen that visual acuity varies from 23 percent to 136 percent, with visual acuity taken as 100 percent for the black object on a white background under the 10-footcandle level. Actually Fig. 41 is obtained from Fig. 26 by taking the reciprocals of the threshold sizes in Fig. 26. It is suggested that the reader compare these two illustrations as an aid to thinking more broadly in terms of visual acuity as well as threshold size.

A few examples may aid in grasping the full significance of such data as presented in Fig. 41. Let us assume that a visual acuity of 100 represents normal vision and that we have seven persons possessing normal vision as determined by the usual test-chart illuminated to a level of 10 footcandles. Suppose we had seven different tasks represented, respectively, by black details viewed against the seven different backgrounds, from dark gray to white, in Fig. 41. Let us assign one of the seven persons to each of the seven tasks. For the 10-footcandle level the visual acuities of these seven persons with normal vision are in effect, respectively, 26, 52, 72, 83, 91, 96 and 100. This is literally true while the seven persons are engaged in their respective tasks, regardless of the fact that they would all have a visual acuity of 100 as determined in the usual manner.

The foregoing reasoning is flawless and even axiomatic. Certainly, it is a fact that the seven visual tasks represent a very wide range in degree of difficulty or relative ease of seeing. Certainly, a person with a visual acuity of 26, compared with a normal of 100, is very greatly handicapped. Similarly, a person working on a visual task represented by the block on the extreme left of Fig. 41 is engaged in a far more severe task than that represented by the block on the extreme right. Aid can be given that person engaged in this severest of the seven tasks which involves black critical details (DRF = 3 percent) on a nearly black background whose diffuse reflection-factor is 3.4 percent, such as sewing with black thread on dark goods and many other visual tasks. Such aid is always available through increasing the level of illumination.

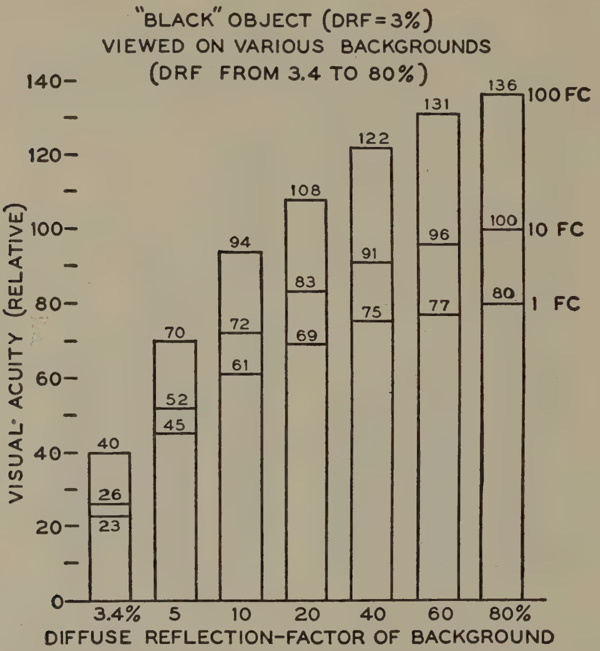


FIG. 41.—The values of visual acuity in this case are proportional, respectively, to the reciprocals of the threshold sizes in Fig. 26. It is seen that visual acuity for a black object increases markedly as the reflection-factor of its background increases. In all cases visual acuity is much higher when the level of illumination is 100 footcandles than it is for the lower footcandle-levels.

Increasing this from 10 to 100 footcandles increases visual acuity from 26 to 40. By increasing the level of illumination to 1000 footcandles, which can be done in practice by applying localized light, visual acuity is raised still further toward normal visual acuity of 100. The brightness of the background in this case, whose DRF is 3.4 percent, will be only 34 footlamberts under a level of illumination of 1000 footcandles. This is a relatively low brightness for it is that of a diffusely reflecting white surface with a DRF of 80 percent illuminated by about 43 footcandles.

The level of illumination of the task represented by the left-hand block of Fig. 41 would have to be increased to 2350 footcandles before it would be as bright as the white background of the right-hand task under 100 footcandles. However, this would only compensate for the low reflection-factor in the former case and not for the lower brightness-contrast. Actually, the level of illumination in the former case would have to be of the order of full sunlight at midday in midsummer, commonly 9000 footcandles, to elevate visual acuity into the vicinity of 100.

Such facts and considerations emphasize, as they do time and again in these chapters, the scientific approach toward lighting practice. They also reveal the empiricism, the crudity and the inadequacy of knowledge in past practices not only involving light but other factors which influence seeing.

BRIGHTNESS AND CONTRAST

In Chapter VII various illustrations deal with threshold size as affected by the brightness of the background and by the brightness-contrast between the object and its background. Inasmuch as visual acuity is determined by the minimum size of an object barely visible under given conditions, data pertaining to threshold size are readily convertible into relative visual acuity.

In Fig. 42 the effect of brightness upon visual acuity is shown for four brightness-contrasts—2, 5, 20 and 100 percent—and for a white background of 3 different brightnesses—1, 10 and 100 footlamberts. It is interesting to compare Fig. 42 with Fig. 29 from which the data were converted into relative visual acuity.

It is seen that the brightness-level markedly influences visual acuity. This fact easily escapes those whose interest in visual acuity is confined to vision and does not extend to various visual tasks and seeing. Furthermore, the importance of brightness-level is particularly emphasized by the lower brightness-contrasts which are not involved in the common black-on-white test-charts.

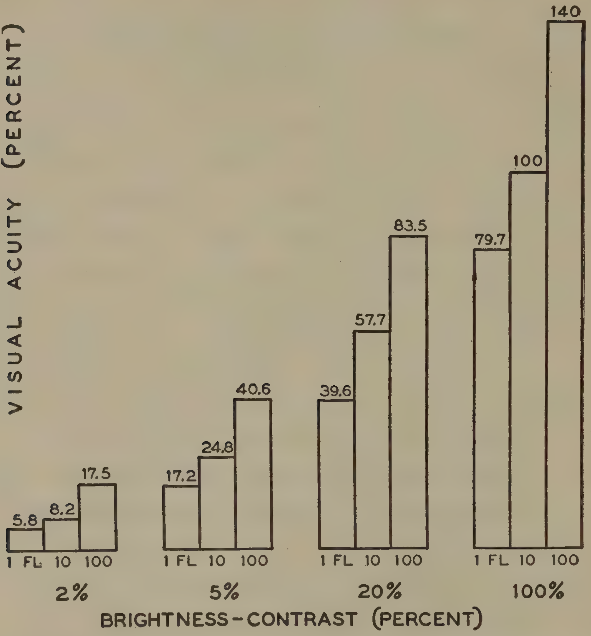


FIG. 42.—Showing how visual acuity is enormously less for objects of low brightness-contrast with their backgrounds than for objects of high brightness-contrasts. Here again the influence of level of illumination is obvious. (See Figs. 30 and 31.)

It is seen in Fig. 42 that relative visual acuity varies, for the range of conditions involved, from 5.8 to 140. Even for one level of brightness—the 10-footlambert level—visual acuity varies from 8.2 to 100. To the eyesight specialist this would represent an enormous range. For two different subjects tested by the same method, the eyesight specialist would properly conclude that a person with the visual acuity of 100 had normal vision and the one with the visual acuity of 8.2 would have extremely poor vision, actually a visual efficiency less than 20 percent by the A.M.A. rating and 20/200 by the Snellen rating. (See Chapter XI.)

There is no denying the fact that a person working on tasks involving very low contrasts has—while working on them—the practical equivalent of very poor visual acuity under ordinary levels of illumination. Nothing more strikingly illustrates the need for very high levels of illumination, or for any other available aid to seeing, for seeing tasks involving fine details, low reflection-factors and particularly low brightness-contrasts.

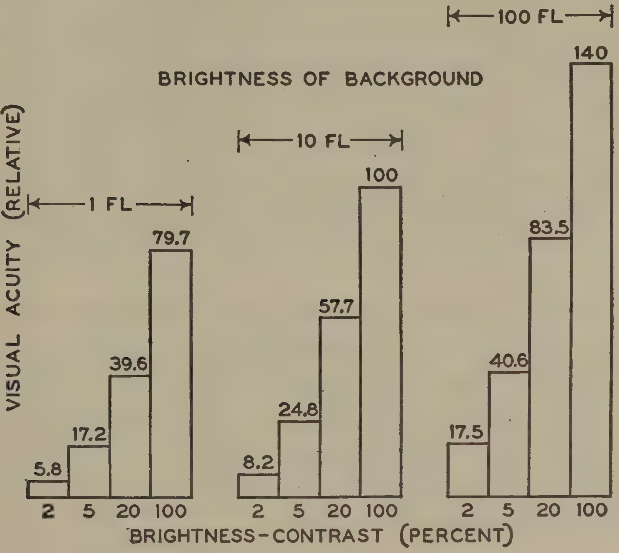


FIG. 43.—Compare these data with the corresponding threshold-sizes presented in Fig. 29 from which the relative visual-acuity values are readily computed. Commonly, for the sake of comparison, we give a value of 100 to visual acuity for a black object viewed against a white background illuminated to a level of 10 footcandles. If the reflection-factor of the background were 100 percent, it would have a brightness of 10 footlamberts.

In Fig. 43, the data presented in Fig. 42 are grouped in a different manner for another view. This shows rather strikingly an upward sweep of visual-acuity values as we look from left to right. Brightness of the background, as produced by the three levels of illumination, plays its part, and overall the effect of increasing brightness-contrast—from very light gray objects to black objects and all viewed against a white background—is strikingly evident.

In the light of the foregoing data, statements to the effect that visual acuity does not increase much above 10 footcandles, or that 10 or 20 footcandles are enough for persons with normal vision, are ridiculous. The only mitigating fact is that generally such statements are made without knowledge of the facts which cannot be obtained by means of ordinary test-charts and other test-objects used by the eyesight specialist for his specific purposes. Such comments are generally the result of applying the limited specialized knowledge of vision to the relatively unlimited world of seeing.

A summary may be helpful at this point in order to see at a glance the effects of the fundamental factors upon threshold size and, therefore, upon visual acuity. We shall assume that objects, varying from very light gray to black, are viewed against a white background. Furthermore, normal visual acuity is 100. For these conditions the range in threshold size, or smallest detail visible, is as follows:

For a range from 1 to 100 footcandles and objects of low contrasts,

Threshold size varies from 15 to 5 minutes.
Visual acuity varies from 6.7 to 20.

For a range from 1 to 100 footcandles and objects of high contrasts,

Threshold size varies from 1.1 to 0.6 minutes.
Visual acuity varies from 90 to 167.

For a range in exposure-time from 0.07 to 0.3 second and objects of low contrasts,

Threshold size varies from 20 to 13 minutes.
Visual acuity varies from 5 to 7.7.

For a range in exposure-time from 0.07 to 0.3 second and objects of high contrasts,

Threshold size varies from 1.3 to 1.1 minutes.
Visual acuity varies from 77 to 90.

For a range of brightness-contrasts, between object and background, of 1 to 100 percent and with 100 footcandles on the background,

Threshold size varies from 20 to 0.6.
Visual acuity varies from 5 to 167.

A review of the foregoing in terms of the countless tasks of seeing reveals enormous opportunities and needs for the services of the seeing specialist.

EFFECT OF PUPIL SIZE

The size of the pupil has been discussed briefly in other chapters but it is important to consider its influence upon visual acuity. Often it is erroneously stated that a small pupil increases visual acuity. Such statements arise from theorizing from knowledge gained with cameras and other optical instruments, without acquaintance with the facts available.

The facts, as presented in Fig. 44 were established by P. W. Cobb in our laboratory many years ago but apparently have been generally overlooked.[23] The higher values are for a constant brightness of the test-object. The lower values are for a constant brightness of the retinal image. This was maintained constant by decreasing the brightness of the test-object to exactly compensate for the increases in the area of the pupil from the 2-millimeter size. It is seen that visual acuity is sensibly the same for pupil sizes ranging from 2 to nearly 6 millimeters in diameter. Inasmuch as a millimeter is equivalent to 0.039 inch, visual acuity is approximately the same for diameters of the pupil ranging from about 8 to 23 hundredths of an inch. This covers the common range of pupil diameters. Furthermore it is seen that visual acuity is much lower when the pupil is still smaller in diameter than 2 millimeters.

As stated elsewhere, the definition or sharpness of an image increases as the aperture of a lens is decreased. On the other hand, the resolution or separation of fine details increases as the aperture of a lens is increased. Apparently these offset each other fairly well in the case of the pupil of the eye. Therefore, the size of the pupil is of chief interest in its admission of light to the retina; that is, in its effect upon the brightness of the retinal image.

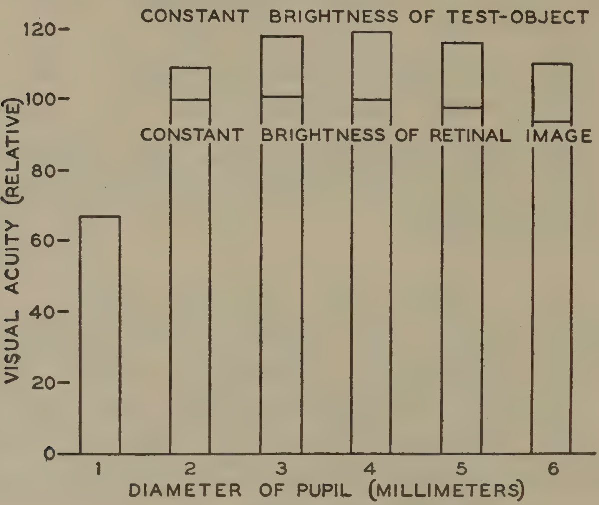


FIG. 44.—Visual acuity, under otherwise constant conditions, does not vary appreciably for quite a range in the size of the pupil. Often it is erroneously assumed or stated that visual acuity increases as the pupil-size decreases. This is not true.

AS EYES GROW OLDER

Older eyes are generally much more defective than younger eyes. However, even if they are fully corrected for socalled refractive errors, their ability in various ways appears to diminish as they grow older. For one reason their pupils become smaller for a given brightness condition. This reduces the brightness of the retinal image, but this does not adequately account for the steady decrease in visual acuity with age. Probably these marvelous visual mechanisms become generally dulled in sensitivity by use and abuse.

At any rate visual acuity declines with age as indicated in Fig. 45. For the sake of comparison the relative visual acuity of average eyes for the age of 20 years is assumed to be 100. On the average, at the age of 40 years this has declined 10 percent or relatively to 90. At ages 60 and 80, visual acuity has declined relatively to 75 and 50, respectively. These values are from various sources and probably only represent the decline with age in a general way.

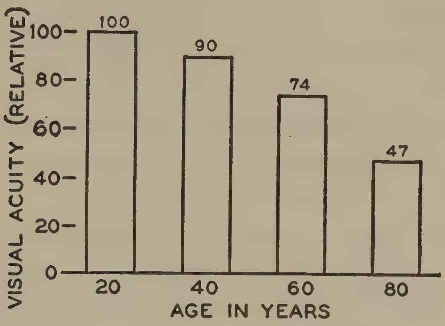


Fig. 45.—The inherent visual acuity of eyes measured under standard conditions decreases markedly with age. These data were obtained by averaging the results of various surveys. Old eyes, on the average, can be aided by increasing the level of illumination as indicated in various illustrations such as Figs. 41, 42 and 43.

It is interesting to consider these decreases in visual acuity with age in terms of what might be done to compensate partially by increasing the level of illumination. In general, it is known that light or any other aid to seeing helps those most who need help most. It is obvious that old eyes can be aided materially by much higher levels of illumination. It has been seen that visual acuity in the case of normal eyes increases about 40 percent when the level of illumination is increased from 10 to 100 footcandles. This is true for tasks involving high contrasts, such as this printed page. Therefore, from Fig. 45 one would conclude to supply at least 100 footcandles for old eyes where 10 footcandles were being used by young eyes for reading. However, 10 footcandles are far from adequate for many tasks performed by the young eyes.

No exact specification can be made for any given case without a thorough test, but it is obvious that old persons generally should have a good deal more light than they ordinarily have available. If one will take the trouble to investigate he will find many old persons performing visual tasks under great handicaps and also many who have given up reading and other activities at night without realizing that in many cases much more light would be very helpful.

There are eye conditions, such as mild cataracts, where the distribution of brightness may be very important. In such cases it is worth while to try providing much light on the task such as a printed page, and surrounding it with a surface of very low reflection-factor. This is not a satisfactory seeing condition in general, but in the special case of cataractous eyes it is desirable to keep light from the eyes excepting that from the task itself. The scattering of useless light inside the eye media, by a cataractous condition, produces a more or less blinding veil of brightness which can greatly reduce the ability to see details such as these words.

For many years the author has advocated that eyesight specialists, whose interest is necessarily in vision, become more interested in seeing. This would be a valuable service to their patients. If they did this they would have to know more about the contributions of light and lighting as aids to seeing. Often they would be in a position to be most helpful to their patients who need more than eye-care and eyeglasses. What they actually need is adequate visibility and reasonable ease of seeing. Obviously these depend upon other factors as well as eyeglasses. For example, visual acuity in its broad sense is not a monopoly of eyesight. It is the result of eyesight *and* visual tasks *and* seeing conditions.

SUBNORMAL VISION

Throughout these chapters we are dealing with normal eyesight unless otherwise stated. All the fundamental data were obtained with representative groups of subjects possessing socalled normal vision, as has been emphasized many times. It would be interesting to extend the investigations to groups possessing subnormal vision of various levels. However, these investigations are tedious and time-consuming and have already extended continuously over several decades.

For the most part we shall have to be content with the knowledge that seeing conditions even for normal vision have been grossly neglected and only vaguely understood. Average vision is below the socalled normal and, therefore, any conclusions arrived at from our fundamental data for normal vision will be even more conservative for average vision, and very much so for those with very subnormal vision who help to make up the average.

In passing it is of interest to note the average results obtained for a group of twenty subjects who wore eyeglasses of "average" corrections. Their visual acuity was carefully determined, with and without their eyeglasses, for three levels of illumination of the test-object, which was black of various sizes on a white background. The averages of the results are shown in Table VIII. For convenience in this case, the relative visual acuity is made equal to 100 at the one-footcandle level. The corrective glasses worn by these subjects were in no case unusual, for all the subjects could see reasonably well without their glasses. It is seen that, without their eyeglasses, relative visual acuities increased from 100 to 120 to 133 when the level of illumination

TABLE VIII

Relative Visual Acuity of Twenty Subjects Who Normally Wore Eyeglasses of Average Corrections, as Affected by Level of Illumination

Illumination of Test-Object	Relative Visual Acuity	
	Without Glasses	With Glasses
1 footcandle	100	123
10 footcandles	120	145
100 footcandles	133	156

was increased from 1 to 10 to 100 footcandles. When wearing their eyeglasses the corresponding relative visual acuities were 123, 145 and 156. Without their eyeglasses visual acuity was increased 33 percent by raising the level of illumination from 1 to 100 footcandles. At the one-footcandle level of illumination, visual acuity was increased only 23 percent by means of the corrective glasses. The contribution of eyeglasses at the higher levels was comparable.

A word of caution is necessary. The foregoing comparison of the relative contributions of light and corrective eyeglasses is introduced to emphasize the value of light as an aid to seeing. There is not the slightest intent to imply that more light is a substitute for eyeglasses if the eyes have appreciable defects of refraction. Both increase the ability to see, as is shown by measurements of visual acuity. Both make seeing easier. However, eyeglasses counteract certain optical errors and overcome certain other shortcomings of defective vision. More light enhances the visibility of the objects to be seen as well as actually extending the abilities and reducing the limitations of the visual sense. Light and sight are essential to seeing in somewhat different ways. They are partners, not substitutes for each other.

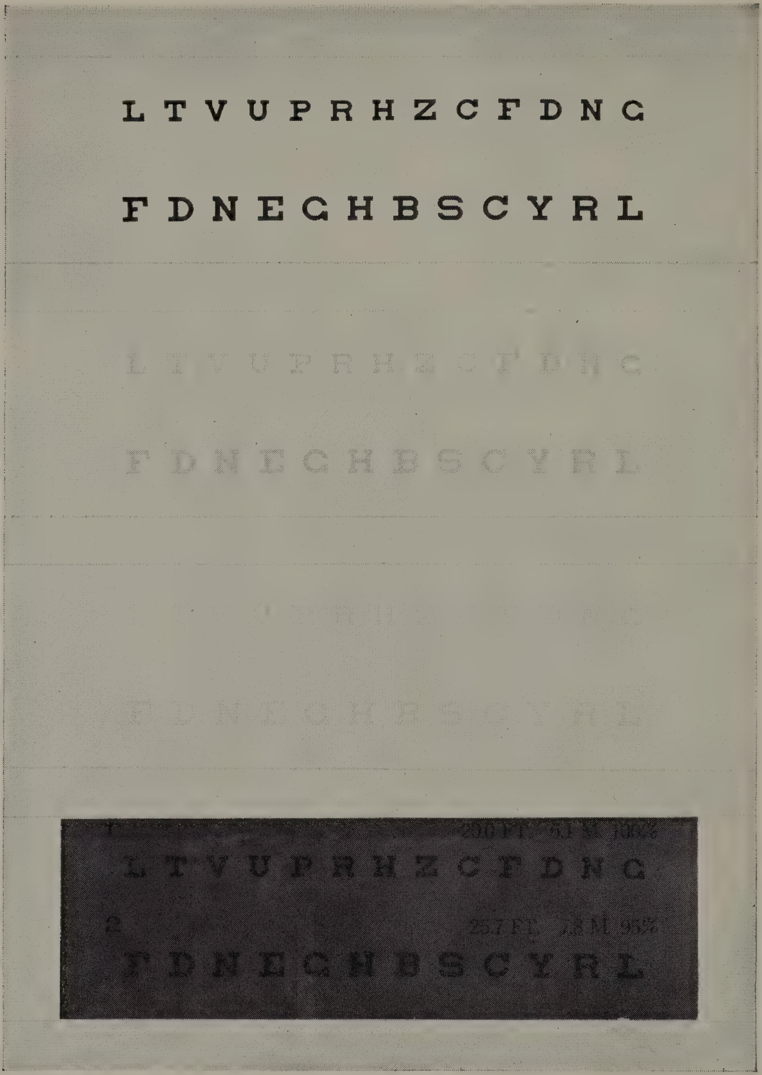


Plate XI.—Lines 1 and 2 of the A.M.A. Test-Chart reduced to one-third size. From top to bottom the pairs of lines represent approximately the brightness-contrasts of the four charts, Nos. 1 to 4, respectively, described in Table IX. At a distance of 7 feet, the top line is readable under 10 footcandles by a person with average normal vision. For the same line on the other test-charts, 100 to 1000 footcandles are generally necessary.

CHAPTER XI

Test-Charts and Their Limitations

Vision and visual ratings are widely associated with the common test-charts used by eyesight specialists, school and industrial nurses, and others for simple tests of vision. These charts serve many useful purposes, if they are properly used and particularly, if their limitations are understood. The common test-chart is not a precision device in any sense of the term. The letters in any given line differ appreciably in visibility. There are not enough lines on the ordinary test-chart to provide small enough steps in size of letters to approach anything like a precision device. In addition to these limitations there is no standardization of the illumination of the chart.

Even with these shortcomings, common test-charts are practicable, within their limitations, because eyes usually possess a degree of reserve, particularly in accommodation. For example, if the eyeglasses are not based upon a perfect or ideal prescription, accommodation can make up the difference if it is not too great. Of course, this applies to the chief purpose of the test-chart, which is to determine the power of the lenses to be prescribed. Accommodation reserve is somewhat analogous to latitude in photographic emulsions. There is a considerable latitude in exposure which has made amateur photography practicable.

The common test-charts, consisting of socalled black characters on a socalled white background, serve very well their specialized purpose. However, data obtained by means of them are of very limited value to the seeing specialist because they are special or limiting examples of countless visual tasks. In common test-charts the contrast between the black test characters and their white background is very high. For a clean test-chart it is generally greater than 95 percent. As has been emphasized in preceding chapters, brightness-contrasts in everyday critcial tasks of seeing range from 0 to 100 percent.

To ophthalmologists and optometrists engaged in examining eyes, and in servicing them with corrective eyeglasses, visual acuity is a very important visual function. Many of them employ various techniques in addition to those involving common test-charts. However, their overwhelming interest in visual acuity and in the specialized task of high brightness-contrast, represented by common test-charts and other test-objects and tasks, has sometimes led eyesight specialists into misinterpretations and erroneous conclusions in connection with the variety of tasks encountered in everyday seeing. For example, many statements have been made to the effect that visual acuity, for persons with normal vision or whose vision has been corrected to normal by means of eyeglasses, does not increase materially above 10 footcandles. Such a statement is incomplete at best and in a practical sense is meaningless.

From the viewpoint of seeing, visual acuity is not an inherent and fixed ability of the eyes. It depends upon the test-object and upon the seeing conditions. For example, we have seen that for tasks involving black details on a nearly black background visual acuity, even for normal vision, may not reach a "normal" value even for levels of illumination of 1000 footcandles or more. In many cases of low brightness-contrast, visual acuity may not even reach a normal value in the illumination of full sunlight which sometimes equals and exceeds 9000 footcandles.

Visual acuity is also overrated in the testing of individuals for night driving and for various occupations involving seeing at night under low brightness-levels. Among these are night flyers, lookouts on ships and all engaged in observation under low brightness-levels. In such cases, high contrast-sensitivity, or the ability to see brightness-differences as small as possible, is generally far more important to safe and certain seeing than visual acuity is. In fact, persons with the same visual acuity, as determined by usual methods, differ widely—commonly as much as 100 percent—in their ability to distinguish small brightness-differences.

THE SNELLEN TEST-CHART

Nearly a century ago Snellen was the first to make a test-chart which had a rational basis. He had found that the threshold size (Fig. 24) of critical details, for most persons with socalled normal vision, was about one minute of visual angle for black objects on a white background. This has since been verified by various investigators.[6] Snellen arbitrarily used plain block letters whose overall height subtended a visual angle of 5 minutes at the eye. However, he made the width of the black lines, of which the letters consist, one minute in visual size or width. In the case of letters, such as E in Fig. 46, spaces between the black parts were also one minute in visual size or width.

Although the Snellen test-chart has taken several forms, a common one is illustrated in Fig. 46. The physical sizes, or heights of all the letters, are such that they are of equal visual size if each is viewed at its specified distances, at which it can barely be recognized by persons with normal vision. The Snellen fraction

$$\text{Visual acuity} = \frac{d}{\mathrm{D}} = \frac{\text{actual distance}}{\text{normal distance}}$$

is important in the Snellen system of rating vision. In this fraction, d is the distance in feet at which a given line of letters is barely recognizable by any subject; and D is the distance in feet at which the same line of letters is barely recognizable by a person with normal vision. Obviously d is always the distance at which the test-chart is actually viewed.

The Snellen test-chart was devised to be used at a distance of 20 feet. This is considered to represent distant-vision. In many cases of defective vision, tests at distant-vision are far from satisfactory for determining refractive errors and for specifying corrective glasses for near-vision tasks. However, for the present this is beside the point.

If at a distance of 20 feet a person can barely recognize the letters in line 8 of the Snellen chart, Fig. 46, he is said to have average normal vision. This is expressed as 20/20 vision in the

Snellen rating. However, if another person can only barely recognize the letters in line 5 he possesses 20/40 vision. One will

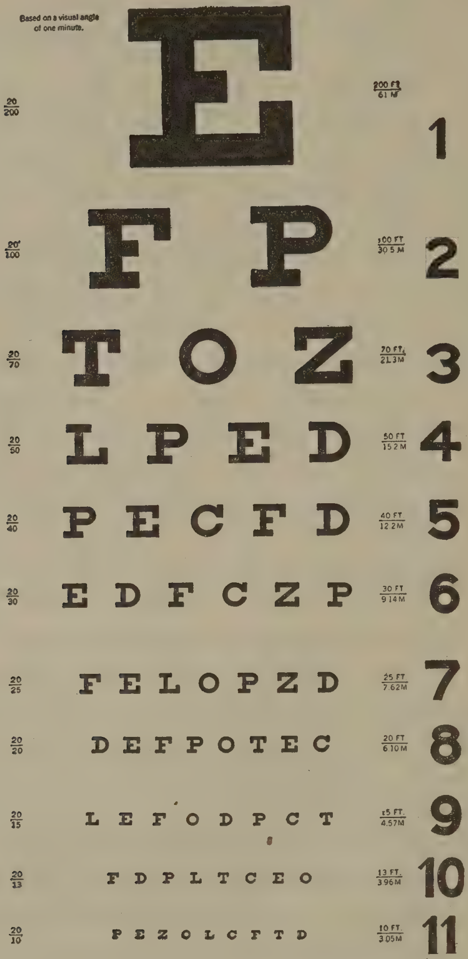


FIG. 46.—A standard Snellen test-chart reduced to about one-fourth size. (See text.)

note from the foregoing simple formula that this subject can barely read line 5 at 20 feet, but a person with average normal vision can just read it at a distance of 40 feet. Therefore, in that formula *d* equals 20 and D equals 40. Thus the Snellen rating for the subject is 20/40.

Inasmuch as some persons have better than average normal vision, lines 9, 10 and 11 are provided. If a person can read line 11 his vision is 20/10 instead of 20/20. Obviously he recognizes letters half the normal threshold size and his visual acuity is twice that of average normal vision. Such cases are relatively rare and they are found more often among persons engaged in outdoor activities such as the lookouts on ships.

If a person can barely distinguish the top line of the Snellen chart, which commonly consists of the block letter E, his vision is 20/200. In other words, he is just able to recognize at 20 feet what a person with normal vision can recognize at 200 feet. Threshold size for him is 10 times normal and his visual acuity is rated as 10 percent of average normal. He is legally blind in various countries.

The metric system is also used to some extent. Inasmuch as 20 feet is approximately equivalent to 6 meters, a Snellen rating of 6/6 in the metric system is approximately equivalent to a 20/20 rating in the system involving distances in feet.

It should be emphasized that 20 feet is an arbitrary distance and has no significance excepting for a test-chart whose letters or other characters are designed in physical sizes to be used at 20 feet. One could make a chart to be used at any specified distance. It is only necessary to use the basic visual angle of one minute. In other words, the common Snellen chart could be used at 100 feet if the letters were increased to five times their present physical size. In this case 100/100 vision would be the rating for average normal vision. However, the Snellen test-chart and other common test-charts are designed for a viewing distance of 20 feet which accounts for the presence of this number in all Snellen ratings of vision.

Test-charts designed for use at distances within arm's reach would require very small letters as illustrated in Fig. 48 for a distance of 14 inches. These would be difficult to reproduce accurately by printing. Therefore, it has been necessary for research purposes to devise other and far more accurate methods for determining threshold size and visual acuity at any distance. Incidentally even for normal eyes, visual acuity is appreciably different for near-vision than for distant-vision. Considering our everyday slavery to tasks of near-vision it appears inevitable that vision will eventually be tested with precision at short range—commonly 14 inches—as well as at 20 feet from the test-objects.

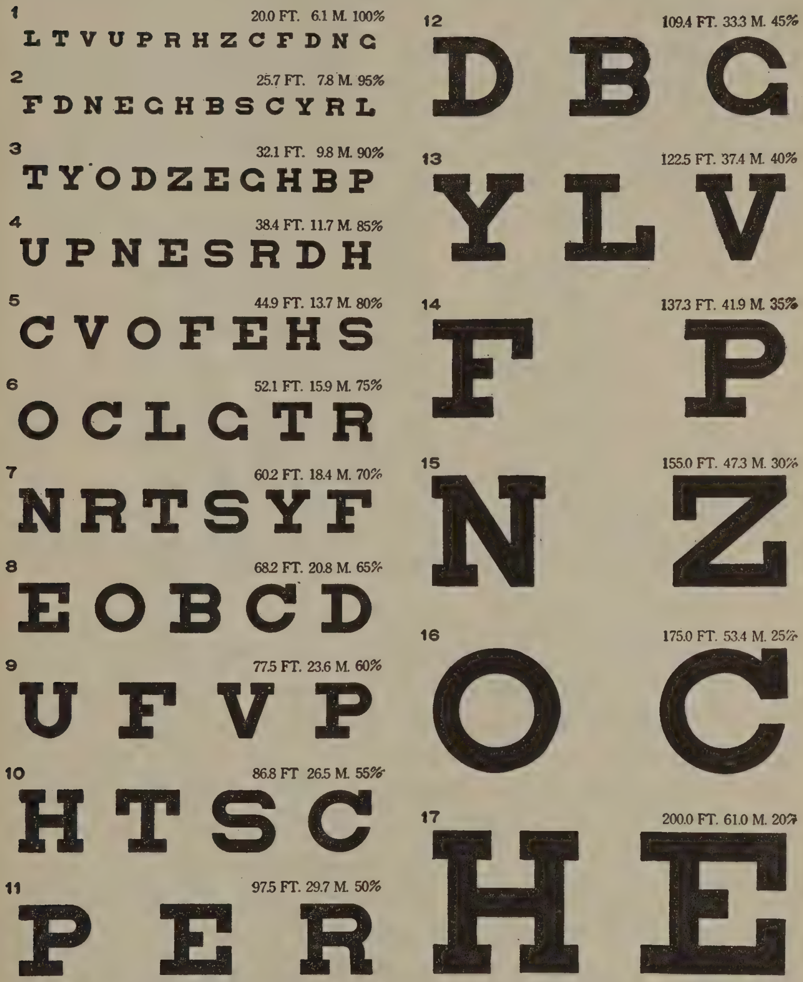
The overall length of the actual Snellen chart illustrated in Fig. 46, from the top of the letter E to the bottom of line 11, is about 20.5 inches but it is about 5 inches in this reproduction. Obviously the reproduction is about one-fourth the size of the original. Therefore, Fig. 46 should be viewed at a distance about one-fourth of 20 feet if the visual sizes are to be the same for Fig. 46 as for the original chart. Actually the proper distance is 4.8 feet as arrived at by the relationship of distance and physical size.

THE A.M.A. TEST-CHART

This consists of 17 lines of letters of different sizes. On one side of the card there are 11 lines with line 1, consisting of the smallest letters, at the top. On the other side of the card are 6 lines of progressively larger letters. Both sides are illustrated in Fig. 47. The overall length of the A.M.A. (American Medical Association) chart from the top of line 1 to the bottom of line 11 is about 22.75 inches. In the reproduction (Fig. 47) it is about 5 inches. Therefore, if Fig. 47 is viewed at a distance of about 4.4 feet from the eye the visual sizes will be the same as though the original chart were viewed at 20 feet. Obviously 5/22.75 of 20 feet is 4.4 feet.

The actual visual sizes of the Snellen and A.M.A. charts as they are viewed at 20 feet are produced if Fig. 48 is held at 14 inches from the eyes.

The sizes of the letters on the A.M.A. chart are designed on the same principle of physical size and distance as in the case of the Snellen chart. For example, to persons possessing average normal vision, the letters in line 1 of the A.M.A. chart are barely recognizable at 20 feet and those in line 17 at 200 feet. The



1 20.0 FT. 6.1 M. 100%

L T V U P R H Z C F D N G

2 25.7 FT. 7.8 M. 95%

F D N E G H B S C Y R L

3 32.1 FT. 9.8 M. 90%

T Y O D Z E G H B P

4 38.4 FT. 11.7 M. 85%

U P N E S R D H

5 44.9 FT. 13.7 M. 80%

C V O F E H S

6 52.1 FT. 15.9 M. 75%

O C L G T R

7 60.2 FT. 18.4 M. 70%

N R T S Y F

8 68.2 FT. 20.8 M. 65%

E O B C D

9 77.5 FT. 23.6 M. 60%

U F V P

10 86.8 FT 26.5 M. 55%

H T S C

11 97.5 FT. 29.7 M. 50%

P E R

12 109.4 FT. 33.3 M. 45%

D B C

13 122.5 FT. 37.4 M. 40%

Y L V

14 137.3 FT. 41.9 M. 35%

F P

15 155.0 FT. 47.3 M. 30%

N Z

16 175.0 FT. 53.4 M. 25%

O C

17 200.0 FT. 61.0 M. 20%

H E

FIG. 47.—Showing both sides of the standard A.M.A. test-chart. For actual size see text.

same Snellen ratings can be used but the A.M.A. chart employs a more or less arbitrary method of rating designated as visual efficiency.

A comparison of the A.M.A. and Snellen ratings is presented in Fig. 49. The 17 lines on the two sides of the A.M.A. test-chart span the same range in size of letters as 8 lines of the Snellen chart. Therefore, the equivalent Snellen rating for the various lines on the A.M.A. chart is not generally a round number. Lines 1 and 17 on the A.M.A. chart correspond, respectively, to lines 8 and 1 of the Snellen chart. In the first column of Fig. 49 are the numbers of the lines on the A.M.A. chart. In the third column are the visual efficiencies as agreed upon by a committee of the American Medical Association. For example, a person who could barely read line 7 of the actual chart, at a distance of 20 feet, would have a visual efficiency of 70 percent of normal. His Snellen rating would be about 20/60, for he could barely read line 7 at 20 feet but a person with normal vision could read it at 60 feet. Obviously, his visual acuity would be one-third of normal, or 33.3 on the basis of 100 as normal.

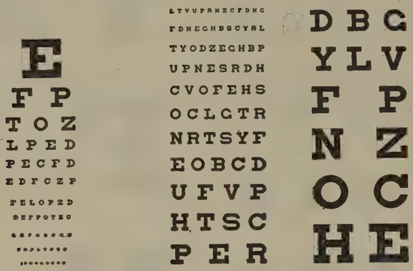


FIG. 48.—If this illustration is viewed at a distance of 14 inches, the visual sizes of the Snellen and A.M.A. test-charts are the same as they are when the original charts are viewed at the proper distance of 20 feet.

It is interesting to convert the Snellen ratings in the fourth column into percent of average normal acuity. This is done by completing the division in each case and multiplying by 100. For example, 20/20 would equal a visual acuity of 100 percent. For line 7, the Snellen fraction 20/60 corresponds to a visual

LINE NUMBER	A. M. A. TEST-CHART	VISUAL EFFICIENCY (PERCENT)	SNELLEN RATING	VISUAL ACUITY (PERCENT)
1	L T V U P R H Z C F D N G	100	20/20	100
2	F D N E G H B S C Y R L	95	20/25.7	78
3	T Y O D Z E G H B P	90	20/32.1	62
4	U P N E S R D H	85	20/38.4	52
5	C V O F E H S	80	20/44.9	44
6	O C L G T R	75	20/52.1	38
7	N R T S Y F	70	20/60.2	33
8	E O B C D	65	20/68.2	29
9	U F V P	60	20/77.5	26
10	H T S C	55	20/86.8	23
11	P E R	50	20/97.5	20
12	D B G	45	20/109.4	19
13	Y L V	40	20/122.5	16
14	F P	35	20/137.3	14
15	N Z	30	20/155	13
16	O C	25	20/175	11
17	H E	20	20/200	10

FIG. 49.—The line-numbers are those of the A.M.A. test-chart, both sides of which are reproduced in a continuous length. In the third column are the A.M.A. ratings of visual efficiency. For comparison the corresponding Snellen ratings and visual-acuity ratings are presented.

acuity of 33 percent. It will be noted that according to the A.M.A. rating for line 7 one has a visual efficiency of 70 percent if his Snellen rating is 20/60 and his visual acuity is 33 percent. As stated heretofore, the A.M.A. system of rating is an arbitrary one based largely upon judgment. One could argue strongly that the visual efficiency of a person depends upon the type of task he is engaged in. For the case just cited, a person with a 20/60 Snellen rating might actually have a "visual efficiency" of 33 percent for some tasks, 100 percent for less critical tasks and zero efficiency for particularly fine work whose details were not recognizable by him.

It is questionable whether an arbitrary rating in visual efficiency is generally as satisfactory as the Snellen and Visual-Acuity ratings. At least these two are not arbitrary. Each rating is definitely based on facts. However, neither of these ratings deals with the visual efficiency of an individual. For example, suppose a person suffers impairment of vision and is entitled to industrial compensation in proportion to his reduced visual efficiency. The A.M.A. rating provides a basis for settlement, however arbitrary it may be.

In any case, regardless of the methods of rating, too much significance is given to them by eyesight specialists compared with a relative neglect of considerations of the visual tasks of everyday seeing. It is necessary to have systems for rating the vision of an individual, but there is no adequate excuse for considering the ability of the eye to be an inherent property of the eye. In everyday seeing, the ability of the visual sense depends very greatly upon external factors such as brightness and illumination, which are always controllable, and upon brightness-contrast which is often controllable.

TEST-CHARTS AND THE RANGE OF VISUAL TASKS

As we have emphasized many times, visual acuity as commonly defined is determined by an arbitrary set of conditions including the use of black test-objects on a white background.

There can be no quarrel with the eyesight specialist in his definition of visual acuity, or with his test-charts or test-objects, as long as he confines them to his special use in examining eyes and in specifying eyeglasses. However, the extreme limitations of these become obvious when interest extends from vision into the far broader field of seeing. We have seen how threshold size and visual acuity are enormously influenced by brightness and brightness-contrast and, therefore, by reflection-factors and levels of illumination. However, let us reveal these relationships by means of some test-charts which are representative of much of the range of everyday visual tasks.

The A.M.A. test-chart was carefully photographed and reproduced with expert techniques on non-glossy photographic paper to exactly the original size. By means of a variety of negatives, of exposures of the prints and of degrees of fogging of the background, one series of test-charts was made consisting of black letters on various backgrounds—white, gray, dark gray and nearly black. Another series was made consisting of white backgrounds but the letters ranged from black, through various grays, to a very light gray. All these test-charts were dry-mounted on thick flat board, and being of the exact size of the A.M.A. test-chart were viewed at the standard distance of 20 feet.

Data pertaining to three of these special test-charts are presented in Table IX. These may be compared with similar data for the standard chart, number 1 on the list. It will be noted that the special charts 2 and 3 had the same white background as the standard chart. However, the letters were medium gray (DRF = 65 percent) for chart 2 and were very light gray (DRF = 76.5 percent) for chart 3. This made the brightness-contrast between the light gray letters and their white background very low. Actually it was only 7.3 percent. This chart might simulate a task of inspecting white cotton goods or other materials for barely perceptible flaws.

Chart 4 had black letters on a background that was nearly black. Obviously, it simulates many tasks such as seeing black thread on dark goods and inspecting very dark materials. It is

TABLE IX

Data Pertaining to Four Test-Charts. Reflection-Factors and Brightness-Contrasts Are Expressed in Percent. The Test-Characters Are Identical in Size and Form on All the Test-Charts. Chart 1 Is the Regulation A.M.A. Test-Chart.

Test-Chart	Diffuse Reflection-Factor Back-ground	Letters	Bright-ness-Contrast
1. Black letters on white background	82.5	2.8	96.5
2. Medium gray letters on white background	82.5	65.0	21.3
3. Light gray letters on white background	82.5	76.5	7.3
4. Black letters on dark gray background	3.3	2.6	21.1

of interest to note that the very important factor, brightness-contrast, was the same for chart 4 as for chart 2.

It is impossible to reproduce these test-charts accurately with half-tones and printing ink. Even accurate reproductions would not take the place of the very pertinent data in Table IX. However, merely as an aid in visualizing these data Plate XI is provided. For this purpose only the first two lines of the A.M.A. test-chart are reproduced one-third size and only approximately in other respects such as reflection-factors of letters and their brightness-contrasts with their backgrounds. From top to bottom they roughly simulate the first two lines of charts 1, 2, 3 and 4, respectively, as indicated in Table IX.

In the actual tests all the 17 lines were used for each of the four test-charts. Inasmuch as the three special charts were exactly the same size of chart 1, the regular A.M.A. test-chart, they were viewed at the standard distance of 20 feet. Twenty subjects, possessing average normal vision, were carefully tested with these charts under controlled conditions at four levels of illumination. Many observations were recorded for each subject on several occasions.

The results are presented in Fig. 50. The clear area in each block represents the lines of letters which could be read by all the subjects in each case. The shaded area of each block represents the "spread" among the subjects. For example, line 1 on chart 1 (the regular A.M.A. test-chart) could be read by a few of the subjects even under the one-footcandle level of illumination. Some could not read a line above line 3. The average limit is indicated by the horizontal line in the shaded area.

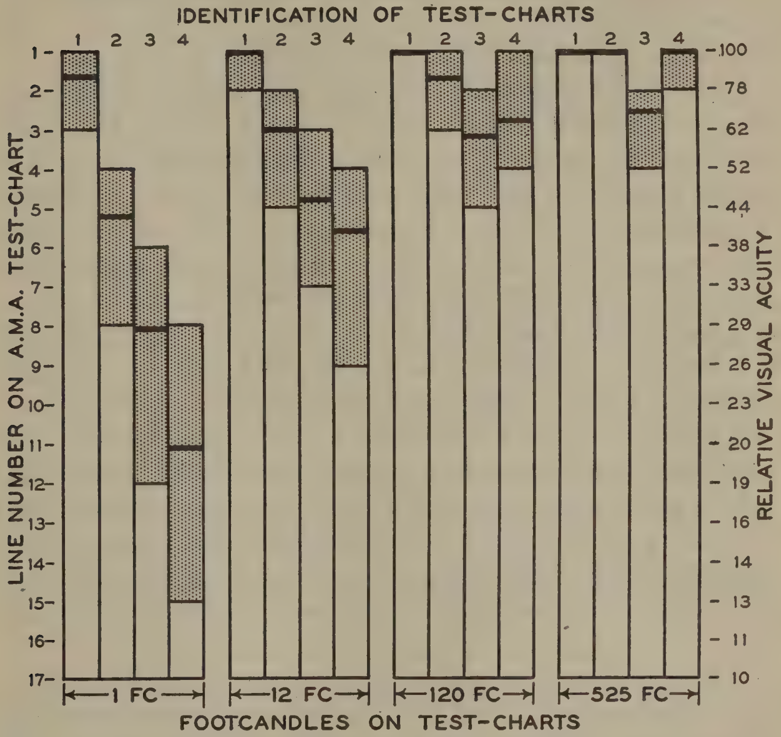


FIG. 50.—The heavy horizontal line in each shaded area represents the average line of smallest letters barely readable by 20 subjects with average normal vision. The shaded areas represent the "spread" for the 20 subjects in each case. Test-chart 1 was the standard A.M.A. chart. Test-charts 2, 3 and 4 were specially made of low brightness-contrasts. (See text and Plate XI.) Note that the top lines on some of the test-charts could not be read at 120 and even 525 footcandles.

Under the 12-footcandle level of illumination all but one subject could read line 1 on chart 1. The one subject could read line 2 but had some trouble reading two or three letters of line 1.

Thus the subjects are seen to have average normal vision. Of course, they could read line 1 of chart 1 at the higher levels of illumination.

It is now interesting to compare the results obtained with the special test-charts and to interpret them with the aid of Fig. 49. First, let us take chart 4 which consisted of black letters on a nearly black background. It is seen that there is a wide spread among the subjects. One could read line 8 and one could only read line 15. Referring to Fig. 49 these represent visual efficiencies of only 65 and 30 percent, respectively, and correspond to visual acuities of about 30 percent and 13 percent of normal. The average line of smallest letters that was barely readable was about line 11 which corresponds to a visual efficiency of 50 percent and a visual acuity of about 20 percent of normal.

Passing on to the 12-footcandle level it is seen that the "spread" for chart 4 decreased somewhat and was between line 4 and line 9. At the 120-footcandle level a few subjects could barely read line 1 and some could only read line 4. The average for the group was about line 3. It is interesting to view the data for chart 4 in the light of one of the many visual tasks which it represents fairly well. Even under a level of illumination of 525 footcandles a few subjects could not read line 1 on this test-chart.

It is interesting to compare the results obtained with charts 2 and 4. As seen in Table IX the brightness-contrast between letters and background was the same for these two test-charts. The only difference was that for chart 2 the background was white (with medium gray letters) and for chart 4 it was nearly black (with black letters). Naturally one would expect that the greater brightness of chart 2, under any given level of illumination, would give it an advantage over chart 4. This is seen to be true for all four levels of illumination. In general smaller letters could be read on chart 2 than on chart 4.

Chart 3, with very light gray letters on a white background, provides another angle of interest. In general, under 1 and 12 footcandles smaller letters could be read on chart 3 than on chart 4. However, at the 120-footcandle level some subjects could read line 1 on chart 4 but none could read line 1 on chart 3. Even the average was slightly higher for chart 4. At the 525-footcandle level none of the subjects could read line 1 on chart 3.

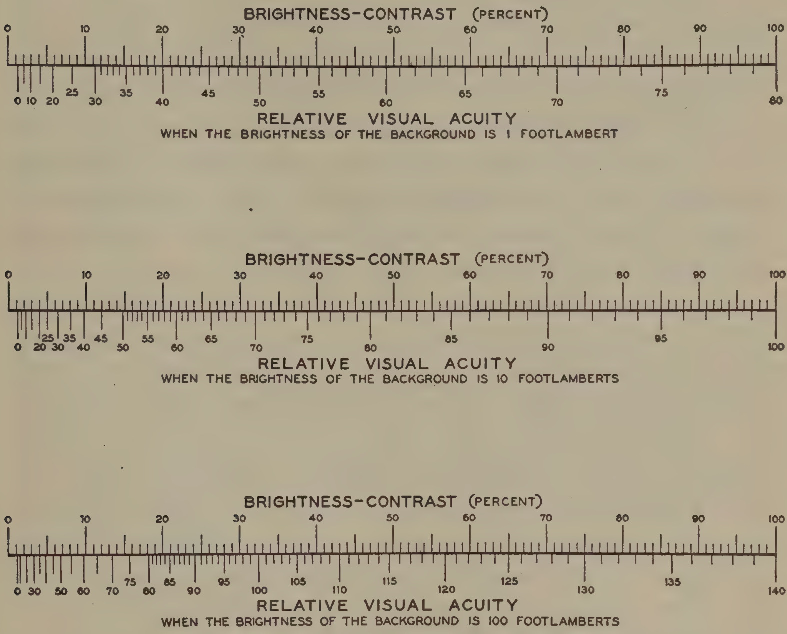


FIG. 51.—Showing the effect of brightness-contrast (of object and its background) upon visual acuity for three levels of illumination—1, 10 and 100 footcandles—as determined for subjects with average normal vision. Visual acuity is 100 for a perfectly black object on a perfectly white background (brightness-contrast 100 percent) when illuminated to a level of 10 footcandles. This illustration covers the entire range of brightness-contrasts for the three brightness-levels of the background. It is interesting to note the increase in visual acuity for a given brightness-contrast as the level of brightness or illumination increases.

The best that any of the subjects could do was to read line 2 and a few of them could only read line 4.

On increasing the level of illumination very considerably—actually to about 2000 footcandles—none could read line 1 on chart 3. In our original work on the four fundamental factors of the visual threshold, it was found that for a brightness-contrast of only 7.3 per cent, as is the case with chart 3, the threshold size for normal vision is greater than one minute even when the white background is illuminated to a level of 200 footcandles. It will be noted that the distinguishing characteristics of the letters in line 1 are about one minute in visual size when viewed at a distance of 20 feet. Probably at higher footcandle-levels other factors, such as irradiation from the white background, also contribute to make line 1 in chart 3 invisible. Thus it is seen that visual acuity, as measured by means of chart 3, can never reach the maximum value obtained with the other charts. This further emphasizes how misleading the narrow concept of visual acuity can be when considering the countless visual tasks involving low brightness-contrasts.

Fig. 50 is worth a good deal of study and particularly in terms of the ratings for the various line numbers in Fig. 49. Certainly the special test-charts 2, 3 and 4 are representative of many everyday visual tasks. There is no denying that a variety of such charts yields data just as pertinent to the vision of individuals *while* those individuals are actually performing tasks represented by the special test-charts, respectively. In fact such special test-charts extend into the world of everyday seeing. It should be obvious that the common test-charts, however valuable they may be in testing vision, provide no data of direct value in considerations of most of our tasks of seeing.

In Fig. 51 are shown the effects upon visual acuity of brightness-contrast (between object and background) for three levels of illumination—1, 10 and 100 footcandles. These scales represent all visual tasks. Note how visual acuity decreases (threshold-size increases) as brightness-contrast decreases; and how it increases with the brightness-level or footcandle-level.

ILLUMINATION OF TEST-CHARTS

Nothing emphasizes more strongly the lack of precision of the common test-chart, and of its use, than the lack of standardization of the level of illumination under which it is used. Excellent treatises on eye-testing in which many techniques and devices are discussed with precision, do not even mention the illumination of the test-chart or of other test-objects. Fortunately test-charts are used indoors and it is likely that the level of illumination is seldom more than 100 footcandles and this could only be obtained if the test-chart were near a window in the daytime. At the other extreme it is probable that the level of illumination is seldom lower than one footcandle. Nevertheless, such a range may mean the difference between passing and not passing certain requirements of vision. Many cases of this sort came to the author's attention during World War II.

Averages of many measurements of visual acuity, involving many subjects possessing average normal vision, yield results as shown in Fig. 40 for our precision test-object when it is black on a white background. The average visual acuities are 78, 100 and 137, respectively, for the three levels of illumination—1, 10 and 100 footcandles. For the sake of easy comparison let us make the relative visual acuity 100 at the 100-footcandle level. We then have the following relative ranges in visual ratings of persons possessing average normal vision for a range of illumination from 1 to 100 footcandles:

Footcandles on test-object	1	100
Relative visual acuity	57	100
Snellen rating	20/40	20/20
Visual efficiency (A.M.A.)	85	100

Besides the interesting foregoing comparisons, the effect of illumination is emphatically demonstrated even for persons with normal vision and for test-objects of high brightness-contrast. Obviously the common test-charts consist of such large steps and eyes commonly possess such accommodation reserve that the effect of level of illumination of the test-chart is not generally noticed. However, it is of measurable importance and in borderline cases the level of illumination is the decisive factor. At any rate there is no valid reason for not standardizing the level of illumination of the test-chart. Without a standard brightness of

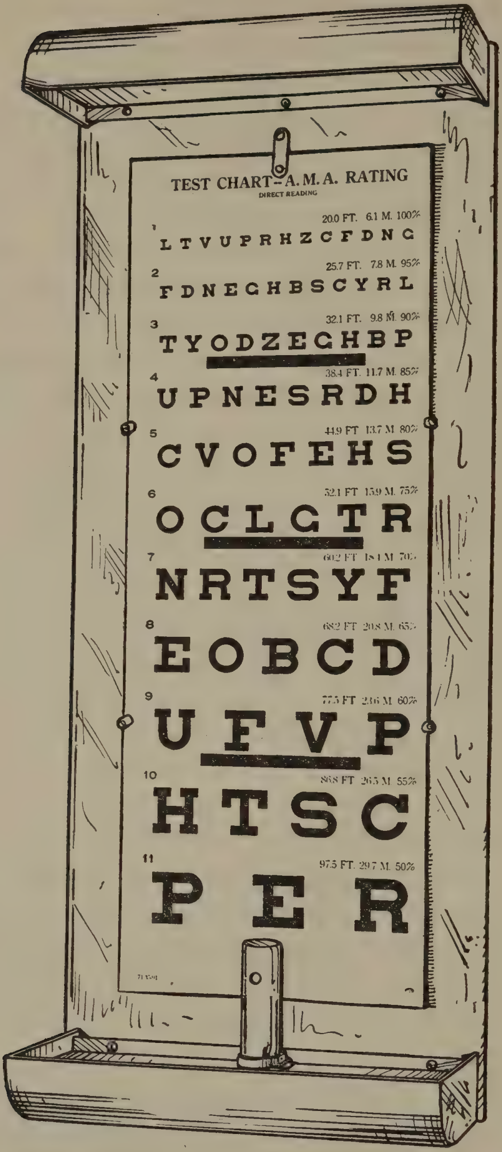


FIG. 52.—The Luckiesh-Moss test-chart illuminator designed for uniformity of brightness, absence of specular reflection and unlikelihood of shadows cast by other light-sources in the room.

the test-chart or test-object, the actual thresholds or borderlines are in doubt.

At the request of an advisory committee of ophthalmologists a test-chart illuminator, illustrated in Fig. 52, was designed. Tubular lamps, containing a single linear filament, are placed at the top and bottom in carefully designed reflectors which produce almost a uniform brightness (plus or minus 20 percent) over the entire test-chart. These locations eliminate undesirable specular reflection into the subject's eyes which commonly results from light-sources on the sides and too close to the vertical edges of the test-chart. The tubular bulbs of the lamps are inside-frosted to diffuse the light slightly. Owing to the complete absence of specular reflection the letters on the test-chart appear strikingly black.

Inasmuch as there should be some general illumination in the room where the illuminated test-chart is being used, attention was given to the avoidance of shadows cast on the test-chart by the reflector housings. Careful consideration resulted in locating the reflector housings above and below instead of at the sides. The metal is finished a dull crackled light gray to reduce the contrast between the test-chart and its immediate surroundings.

CHAPTER XII

Meaning and Measurement of Visibility

All things that are visible are not equally visible. Some critical details on this page of printed matter are barely visible to persons with normal vision while the letters are far above threshold size for the usual reading distance and ordinary seeing conditions. For persons with uncorrected defective vision some or many of the details may be invisible. As the level of illumination is diminished, one detail after another sinks below the threshold into the world of invisibility. Certainly, we need to know more than that an object is visible or a visual task can be performed.

Watch an airplane flying past. At first it is highly visible, just as its roaring motor is highly audible. As its distance increases, its visual size rapidly diminishes. As it bores farther into the ocean of atmosphere, the veiling haze between it and us increases and, consequently, its brightness-contrast decreases. Eventually its size and contrast have so diminished that it approaches the threshold of visibility. Then we may see it or not, as our eyes try to follow it. Eventually it recedes into the vast world of invisibility. Similarly, its roar diminished rapidly until its sound passed the threshold of hearing and entered the world of inaudibility. The distance at which it could not be heard depends upon the hearing conditions. Likewise, visibility depends upon the seeing conditions.

Imagine that we are looking out of a window at an industrial area spreading out into the distance. High chimneys relatively nearby appear large, well defined and of high brightness-contrast with their backgrounds of sky. Distant chimneys, although just as large in actual physical sizes, appear small because their visual sizes are small. Their contrasts with their backgrounds are low,

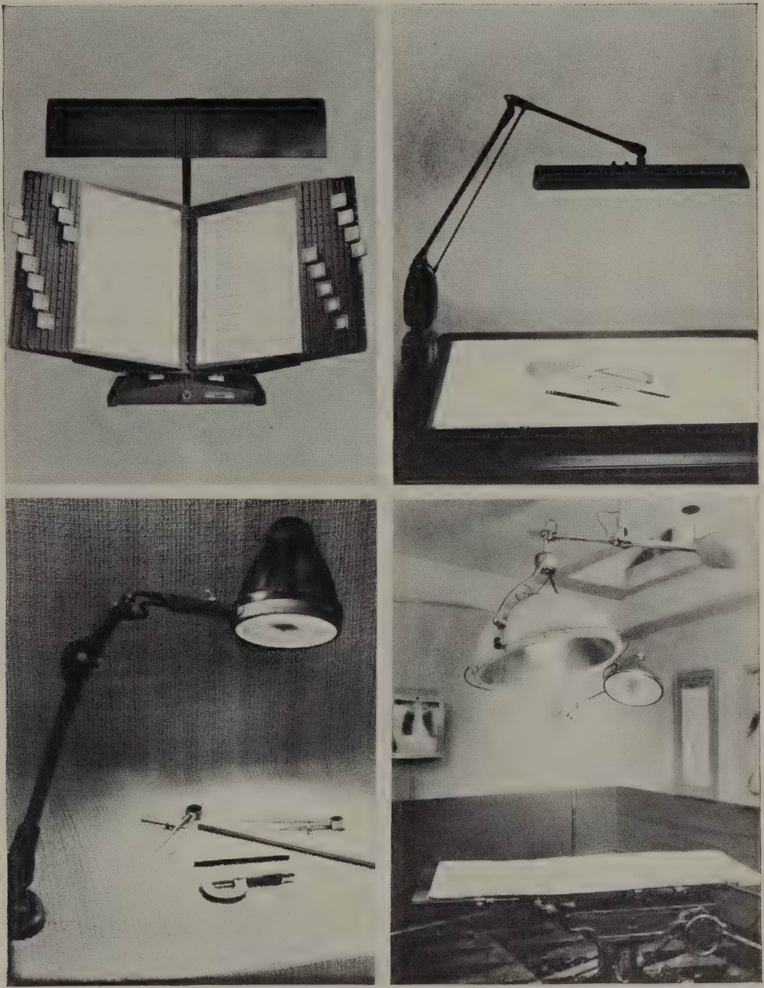


PLATE XII.—General illumination is always necessary for safe and comfortable seeing. In addition to this, supplementary lighting can be fitted to specific tasks of seeing. By this combination, really high levels of illumination, of properly directed and diffused light, become practicable. This is the universal way toward high visibility and easy seeing.

for the haze of the industrial atmosphere is a luminous veil, similar to a thin fog, hanging between us and those distant chimneys. All the chimneys that we can see are visible, of course, *but they are not equally visible.*

If we gaze at the chimneys intently with nothing else engaging our attention, we see all of them that are above the threshold of visibility. If some of our attention or "sense capacity" is otherwise engaged, we see fewer chimneys. If we limit our gaze to a very brief period, by means of a photographic shutter or otherwise, we will be able to see only the larger or more conspicuous—those of higher visibilities. If the sun were shining in our eyes, those chimneys near the line of vision would be rendered invisible by the glare. If the atmosphere grew hazier, as a fog becomes denser, the distant chimneys would become invisible one by one. If we gazed at this scene in the evening as dusk deepened, one after another the chimneys would sink below the threshold of visibility.

These examples are introduced for several purposes. They illustrate that visibility always depends upon the four fundamental factors—size, brightness-level, brightness-contrast and time. They also suggest that other factors may be present, such as glare, which affect seeing conditions. They emphasize the facts that threshold visibility is a limiting and fairly definite condition of barely seeing and that this is influenced by various factors. But above all, they introduce the very important concept of supra-threshold visibility, by directing attention to the fact that all objects, tasks or critical details that are visible are not equally visible. They provide us with a beginning of the very important approach to the long-neglected matter of defining and measuring visibility.

BORDERLINE SEEING

In Fig. 9, and in the discussion pertaining to it in Chapter V, it is emphasized that, for any given seeing condition, each of the four fundamental factors must have a certain value in order that an object be visible. In other words, the size of an object, its contrast with its background, its brightness or more generally that of its background, and the time available for seeing must each exceed a certain individual value, if the object is to be visible. From Chapter V to the present one, many typical data have been presented which emphasize the influence of the four factors upon threshold visibility or barely seeing. In later chapters, secondary factors are discussed, such as glare, direction of light and distribution of brightness in the visual field, which affect visibility directly or indirectly by affecting seeing conditions. Color is discussed in Chapter XV.

Certainly none of us is satisfied merely to barely see an object or to be barely able to perform a seeing task. In fact, this is a situation of which we are always conscious. If the print on this page were so small that we could barely read it, we would be immediately conscious of the difficulty, and eventually of the resulting strain. At first we might be merely annoyed, but eventually we would be fatigued in various ways. The same would be true if the level of illumination were so low that we could barely read. We should feel the same about performing any other task which is barely visible. However, we do not realize how close to the threshold of barely seeing many objects and tasks are.

One primary purpose of Chapters V to XI is to make us conscious of this fact. For example, the printed matter of this page, under ordinary levels of illumination, has a visibility generally far above threshold compared with many tasks that are performed daily for long periods. And if, in the performance of our countless tasks, certain objects or critical details are invisible we simply do not see them. We pay whatever penalties are in store for not seeing them at all, if they are invisible; or for not seeing quickly, easily, or accurately enough if they are of low visibility.

As has been emphasized heretofore, we can fairly well determine a borderline condition. By reducing size, brightness, brightness-contrast, or time, we can determine from an average of a series of trials, when an object can barely be seen or a visual task can barely be performed. However, if we increase visibility above this threshold we are utterly unable to estimate how visible an object or task is. We need some means of determining suprathreshold visibility. Any device to aid us must involve some means of bringing the visibility of the object down to threshold. Therefore, while we cannot possibly be content to barely see in the performance of this task of reading or of any other task for long periods, threshold visibility is the only condition that we, as human seeing-machines, can recognize with reasonable certainty.

How far above threshold visibility is a given object or task? What is the visibility of the print on this page? How does the boldness of type affect its visibility? What should the level of illumination be on this page to raise this reading matter to a given standard of visibility? How does glossy paper or glare affect visibility? What is the visibility of another task, such as sewing, compared with the visibility of this printed matter?

These and countless other questions pertaining to objects and tasks remain unanswered without a means of measuring visibility in terms of some standard unit or degree of visibility.

DEFINING VISIBILITY

Let us return to the chimneys in the industrial setting. We know from preceding chapters that brightness-contrast is a very influential factor in visibility. By varying brightness-contrast we can alter the visibility of an object or task very effectively. Suppose, as we look out of the window at the chimneys, we could increase the atmospheric haze at will, and by measured amounts. We could reduce any chimney to threshold visibility or to a condition so that we could just barely see it.

Now suppose we have a device which we can place before our eyes by means of which we can produce any desired degree of haze or luminous veil between us and the object. By means of such a device we can reduce one chimney after another to threshold visibility just as a thickening fog does. Our measure of how much a given chimney is above threshold is determined by how much of an artificial veil we have to use in order to bring it down to threshold visibility which we have the ability to recognize quite accurately. Owing to the fact that we are *human* seeing-machines it is necessary to make a number of settings of our device and to take an average. This is an inherent characteristic of any measurements a human being makes in which the estimates of his own senses are involved. It is true in using a tape measure, a micrometer or any other device involving seeing. Obviously some estimates are far more difficult than others.

It is seen that the measurement of visibility is necessarily based upon appraisals made under threshold conditions. Also it must be assumed to be axiomatic that

1. Two objects, however dissimilar they may be in size, form, contrast, color or any other characteristic, are equal in visibility when both are barely visible; that is, when both are of threshold visibility.

2. Two objects are equally above threshold visibility when their visibility has been increased by the same increase in one of the four fundamental factors—size, brightness, brightness-contrast or time.

3. The visibility of an object, or degree of supra-threshold visibility, is proportional to the decrease in any one of the fundamental factors necessary to reduce the object to threshold visibility.

The foregoing assumptions are so essential and unavoidable that they may be considered axiomatic. Defense of them is as unnecessary as arguments against them are futile. We are merely forced to such axiomatic assumptions if we are to do anything about defining and measuring visibility.

Reviewing the foregoing, it is seen that we could reduce any visual object or task to threshold by decreasing size until we could barely see the object or could barely perform the task. We could reduce the brightness or level of illumination until we could barely see the object or could barely perform the task. Or we could vary the viewing-time. With a background of decades of research and experience in seeing, we chose to use the highly sensitive factor—brightness-contrast—as the primary variable for measuring visibility.

LUCKIESH-MOSS VISIBILITY METER

The results of many years of research laid the foundation for this device. Its development, calibration and various scales have been extensively discussed heretofore in many appropriate publications.[1, 6] Here only the essential highlights of its principles and uses are presented. It was primarily developed as a laboratory device to be used under properly controlled conditions.[24] However, it can be used in the field if the same precautions are used.

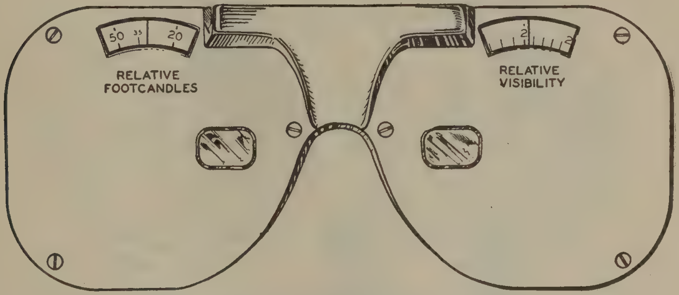


FIG. 53.—The portable Luckiesh-Moss Visibility Meter.

In this respect it is no different than many other devices. It is not a complete answer to all the complex problems of seeing but it is invaluable in many ways. When used properly and with an adequate understanding of its principles, it provides a perfect solution of many of the problems of visibility, and its provides a fairly practical solution to many others. Such a device is essential to research in many phases of vision and seeing. It provides a sound basis for specifications of any aid to seeing.

The simplest portable variety of this visibility meter is illustrated in Fig. 53. This is a binocular device consisting essentially of two identical circular gradients, illustrated in Fig. 54. These are rotated together and alter the brightness-contrast of the object or task whose visibility is to be measured. Although many experiments have been made with other materials, up to the present time photographic gradients are the most practicable. The diffusing property of the film varies with the density of the gradient. Obviously, this variable veil of brightness makes it possible to vary the brightness-contrast of the object or task and, therefore, to reduce it to threshold visibility. Owing to the fact that the photographic gradients also vary in density or transmission-factor, the brightness of the object and its background is also varied. This additional variable is unnecessary but it is inherent in gradients made of photographic film. However, its effects are accounted for in the process of calibration of the device.

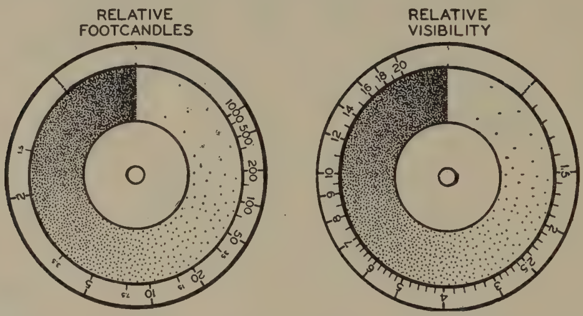


Fig. 54.—Illustrating the two circular gradients and their scales, as used in the Luckiesh-Moss visibility meter.

The principles of the simple portable visibility meter illustrated in Fig. 53 have also been incorporated into precision laboratory models [1] of much more elaborate designs. All laboratory measurements with any of these devices are made under similar controlled conditions under which the devices have been calibrated. However, this is not essential in determining the relative visibilities of various objects or tasks provided certain precautions are taken or that the brightness of the field in front of the device is reasonably constant in area and magnitude. The limitations will become evident from the discussion of the calibration and uses of the visibility meter.

The calibration is in terms of known sizes of our parallel-bar test-object. They were black on a white background, as illustrated in Fig. 55, and were illuminated to a level of 10 footcandles. If that illustration is viewed at a distance of 5 feet the numbers on the various test-objects indicate the visual sizes, in minutes, of the critical detail—the width of the space between the bars. A suitable number of subjects possessing normal vision made many settings of the gradients for each of the series of test-objects. The setting in each case was such that the test-object was barely visible. In this manner, the scale of the right-hand gradient in Fig. 54 was determined.

When the scale of relative visibility is set at 4, for example, the 4-minute test-object illuminated by 10 footcandles is barely visible to persons possessing average normal vision. In other words, all one needs to do to familiarize himself with the meaning of the visibility measurements is to visualize the test-objects illustrated in Fig. 55. One will very quickly be able to grasp the meaning and magnitude of the relative visibility, or RV values, just as he has become familiar with the magnitude of the foot, the pound, the quart and other familiar units of measurement.

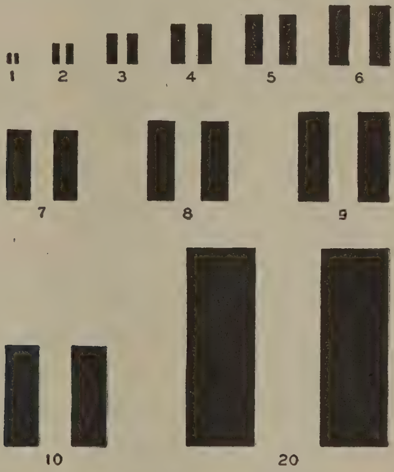


FIG. 55.—The numbers indicate the visual size (in minutes visual angle of the critical detail) of the test-objects used in calibrating the scale of relative visibility (RV) on the L-M visibility meter. If this illustration is viewed at a distance of 5 feet, the test-objects are actually of fthe visual sizes indicated.

It will be noted that the scale of relative visibility begins at 1 and ends at 20. It will be recalled that a critical detail, having a visual size of one minute and illuminated to 10 footcandles, is the smallest that is visible by persons possessing average normal vision. For our parallel-bar test-object the critical detail is the space between the bars. The test-object whose critical detail has a visual size of 20 minutes, Fig. 55, is 60 minutes in overall visual size. (See Fig. 24.) The image of an object of this size just about covers the fovea of the retina, which is the region of high visual acuity. Therefore, it is seen that the scale of relative visibility has a rational basis at both ends, and it is no more arbitrary from one end to the other than the scale of a thermometer or yardstick.

Now that the instrument is calibrated and ready for use under standardized or controlled conditions, it is possible to measure the visibility of any object or task. However, it is best to provide a standard condition for viewing the objects or tasks. Inasmuch as the gradients of the visibility meter are necessarily slightly diffusing, extraneous light should be controlled. When practicable, the simplest way to do this is to have the field surrounding the object or task whose visibility is to be measured, either black or of constant brightness. Other expedients are available when this is impracticable.

Suppose this printed matter under any given level of illumination is found to have a relative visibility of 5 when viewed at a given distance, for example, 14 inches. This means that its visibility under the conditions of measurement and for the particular person who made the measurement, regardless of the status of his vision, is the same as the visibility of our 5-minute test-object under 10 footcandles of illumination for persons possessing average normal vision.

EQUIVALENT TYPE-SIZE

It is not difficult to become familiar with the actual magnitudes of the visibility units and scale in terms of the objects illustrated in Fig. 55. However, most persons are more or less familiar with type-sizes and, therefore, it is helpful to compare the values of relative visibility, RV, with the type-sizes of corresponding visibilities. Those who are not familiar with type-sizes might refer to Figs. 22 and 23, and also to some specimens included later in this chapter. Type-size is expressed in points, a point being approximately one seventy-second of an inch. The size of type, expressed in points, includes the vertical distance from the top of the tallest "ascender" to the bottom of the longest "descender."

In Fig. 56 are shown the relative visibilities of various sizes of a specific type-face (Bodoni Book) when printed with black ink on white paper, illuminated to a level of 10 footcandles and viewed at 14 inches by persons possessing average normal vision. It is seen that the visibility or RV of the 3-point type is close to 1, which indicates that this is about the smallest type readable by persons with average normal vision under an illumination of 10 footcandles. The body-type of newspapers is commonly less than 8-point. From Fig. 56 it is seen that the relative visibility of the 8-point type viewed under 10 footcandles at a distance of 14 inches is, in effect, only 3.7 times the minimum visibility for normal vision. This is not much of a factor of safety considering the many readers with subnormal vision and the commonly poor lighting conditions. Actually the visibility can be increased to about twice this value, or to RV = 8, by increasing the level of

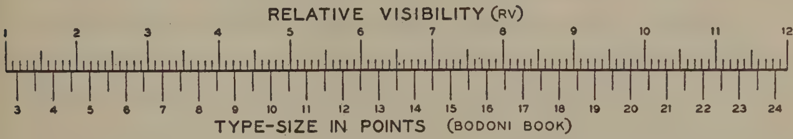


FIG. 56.—Showing the relative visibility (RV) of various sizes of Bodoni Book type printed with black ink on excellent non-glossy white paper and illuminated to a level of 10 footcandles.

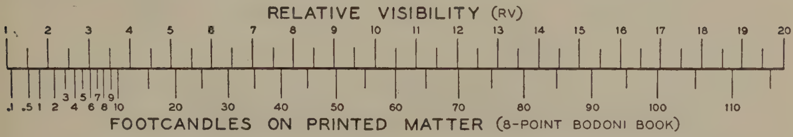


FIG. 57.—Showing the relative visibility (RV) of 8-point Bodoni Book type (printed with black ink on white paper) for various footcandle-levels.

illumination to 42 footcandles. This is indicated in Fig. 57 in which the visibilities of 8-point Bodoni Book type, viewed at a distance of 14 inches, are shown for various levels of illumination for the range up to 115 footcandles. An illumination level of more than 100 footcandles is necessary to increase the visibility or RV to 20. This is the other end of our scale of visibility which we consider a practical maximum visibility for critical seeing.

VARIOUS SEE-LEVELS

Another scale—relative footcandles—on our visibility meter is illustrated in Fig. 53 and Fig. 54. This scale indicates the footcandles required upon any given object to produce a visibility equal to that of 8-point Bodoni Book type illuminated to 10 footcandles and viewed at a distance of 14 inches by persons with normal vision. Any other standard of visibility could be used. For example, the standard of visibility might be that of 12-point type illuminated to a level of 20 footcandles. In this case, the footcandle values on the scale of relative footcandles would have to be multiplied by 5. In all cases the type is assumed to be printed with black ink on excellent white paper.

Before discussing possible standards of visibility or see-levels, a few specimens of common type-sizes should be helpful in visualizing the RV values.

This paragraph is set in 6-point type. It must be illuminated to a level of about 125 footcandles to be equal in visibility to 12-point type illuminated to a level of 20 footcandles. It must be illuminated to a level of 25 footcandles to be equal in visibility to 8-point type illuminated to a level of 10 footcandles.

This paragraph is set in 8-point type. It must be illuminated to a level of about 50 footcandles to be equal in visibility to 12-point type illuminated to a level of 20 footcandles. The relative visibility (RV) of each would be 9 on our visibility meter.

This paragraph is set in 10-point type. It must be illuminated to a level of about 30 footcandles to be equal in visibility to 12-point type illuminated to a level of 20 footcandles. For the same visibility about 50 footcandles are required on 8-point type.

This paragraph is set in 12-point type. This size of type approaches the ideal for prolonged reading by adults with normal vision. A level of illumination of 20 footcandles is conservative for such a visual task. Both the type-size and footcandle-level should be minimums recommended for children. Obviously for subnormal vision, this standard may be conservative or even inadequate.

A number of possible standards of visibility are considered herewith. The values of relative visibility (RV) are for persons possessing average normal vision. The RV values may be appraised from the viewpoint of "factors of safety" in seeing which are desirable to compensate for low visibility due to such factors as defective or uncorrected vision, low levels of illumination, improper lighting and generally poor seeing conditions. When RV = 1 there is no factor of safety even for persons possessing normal vision. In the following we assume printing with non-glossy black ink on excellent non-glossy white paper as well as the foregoing conditions. The levels of illumination were determined by the visibility meter in each case. Those for 8-point type can be checked by referring to Fig. 57.

For RV = 1
    0.05 footcandle on 8-point type
    0.5 footcandle on 4-point type

For RV = 2
    1.5 footcandles on 8-point type
    4 footcandles on 6-point type
    20 footcandles on 4-point type

For RV = 4
    12 footcandles on 8-point type
    30 footcandles on 6-point type

For RV = 8
    17 footcandles on 12-point type
    42 footcandles on 8-point type
    100 footcandles on 6-point type

For RV = 16
    15 footcandles on 24-point type
    20 footcandles on 18-point type

40 footcandles on 12-point type
100 footcandles on 8-point type
225 footcandles on 6-point type

The foregoing should aid in choosing a reasonable see-level or standard of visibility for adults, for children, for persons with defective vision and for sight-saving pupils. It should be evident that a standard of RV = 4 is very conservative even for adults with normal vision. Even to attain this see-level many common tasks require 100 footcandles or more.

A more desirable see-level is RV = 8 from the viewpoints of ease of seeing, of prolonged critical seeing, of old eyes and of average vision which is actually subnormal.

A see-level of RV = 16 is low for sight-saving pupils and for others with decidedly subnormal vision.

Fig. 58 may aid in visualizing various see-levels for persons with normal vision and for two degrees of subnormal vision (Fig. 49). A visual efficiency of 83 percent or a Snellen rating of 20/40 vision is probably a conservative estimate of the average vision of all adult persons. A large percentage of adults, without corrective eyeglasses, will rate as low as 58 percent in visual efficiency or 20/80 by the Snellen chart. For convenience these three groups are designated as A, B and C, respectively.

In Fig. 58 the see-levels are indicated by the 8-point type illuminated to five different footcandle-levels. For each of the three vision ratings, the corresponding RV values are given. For persons with average normal vision, group A, the see-level of barely seeing is obviously RV = 1. As has been emphasized, a see-level of RV = 4 is conservative for normal vision. It represents a visibility of all tasks to be performed by adults with normal vision, equivalent to the visibility of our standard 8-point type, printed with black ink on white paper, illuminated to 12 footcandles, and viewed at a distance of 14 inches.

Now let us consider the group B with a visual efficiency of 83 percent, which probably is a conservative average of adult vision, even including all who are wearing corrective eyeglasses.

It is seen that the threshold or level of barely seeing has moved upward. An RV of 1 for group B corresponds to an RV of 2 for group A with socalled normal vision. Similarly a see-level of RV = 2 for group B corresponds to the conservative see-level, RV = 4, for group A. Actually, 8-point type illuminated to a level of 100 footcandles represents the same see-level (RV = 8) for group B as 42 footcandles on 8-point type (or only 17 footcandles on 12-point type) represents for group A. Incidentally, the latter standard of visibility is far below the optimum of easiest seeing for adults with normal vision. Anyone who seriously experiments with illumination for reading will scarcely argue that 20 footcandles on this page and 17 footcandles on 12-point type are not desirable levels of illumination for prolonged reading.

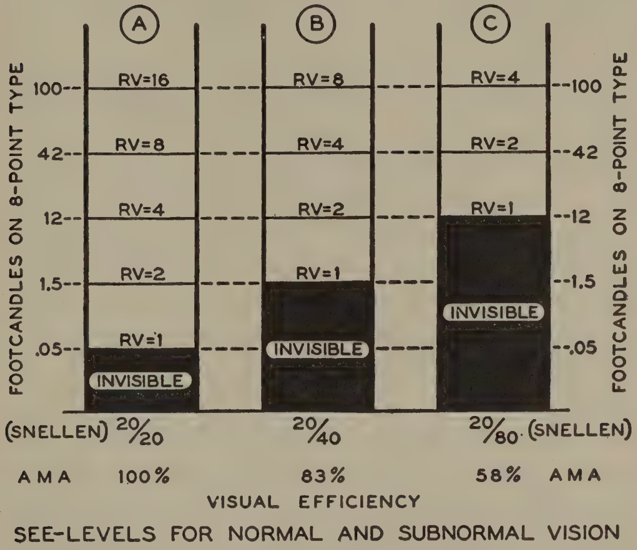


FIG. 58.—Illustrating several standards of visibility (RV) of visual tasks, or see-levels. These may be visualized by the corresponding footcandle-levels upon 8-point type printed with black ink on white paper. Column A is for persons with average normal vision. Columns B and C are for two common degrees of visual deficiency.

For group C in Fig. 58 the threshold or level of barely seeing has moved upward still farther. A see-level of RV = 4 for group A becomes the threshold level for group C. A see-level of RV = 4 for group C, represented by 8-point type illuminated to a level of 100 footcandles, is equivalent to the very conservative see-level for group A, represented by only 12 footcandles on 8-point type.

Fig. 58 graphically depicts neglected aspects of light and vision as they combine to influence visibility. The various see-levels for persons with normal vision can be visualized not only as factors of safety or as different degrees of ease of seeing. They can be visualized in terms of threshold see-levels for persons with various degrees of subnormal vision.

After establishing a standard of visibility or desirable see-level to be attained if possible for all tasks, it is seen that specifications of light and lighting and other aids to seeing can be based upon visibility measurements. At present there is no other method or means. Therefore, specifications that are not based upon meaningful visibility measurements are certainly unscientific. In fact, they are little more than guesses based upon doubtful experience, for we are inherently unable to make estimates with any necessary degree of accuracy. By the methods outlined in this chapter, the seeing specialist can design for specific seeing tasks, just as the bridge-designer designs a bridge to carry a given load over a given span with a reasonable factor of safety.

FOOTCANDLES FOR EQUAL VISIBILITY

Obviously another useful scale is that of footcandles required to bring various tasks to the same see-level; that is, to make all of them equal in visibility to a standard visibility or RV. It is difficult, and even impossible in many cases, to describe visual tasks adequately. However, a few examples are presented in Fig. 59. The visibilities were determined under controlled conditions of brightness. In other words, the necessary precautions in the use of the visibility meter were taken. In this case the standard of visibility (RV = 3.7) is a conservative one, equivalent to that of 8-point type, illuminated to a level of 10 footcandles, and viewed at 14 inches by persons with normal vision. It is seen that 30 footcandles are necessary for common text matter of a newspaper, 100 footcandles for "white" thread on "white" crepe cloth and about 425 footcandles for "black" thread on "black" cloth.

If the standard of visibility were raised to RV = 9, slightly more than that of the printed matter on this page illuminated to 20 footcandles, the footcandle values in Fig. 59 would have to be increased to five times their values (see Fig. 57). From the foregoing section it is seen that 20 footcandles on 12-point type is still only a moderate standard and this fact becomes even more obvious in later considerations of ease of seeing.

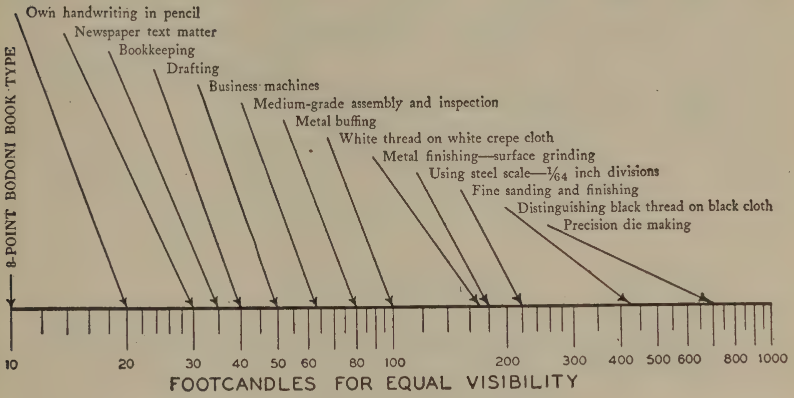


FIG. 59.—Showing the footcandle-level to make each task of the same visibility or see-level as 8-point Bodoni Book type (printed with black ink on white paper) is when illuminated to a level of 10 footcandles. This is a very conservative standard of visibility (approximately RV = 4 in Fig. 58). As seen in Fig. 55 it represents a "factor of safety" of about 4 in size. For persons with a visual efficiency as in Column C, Fig. 58, this corresponds to RV = 1 with no factor of safety.

PERCENT OF MAXIMUM VISIBILITY

It is always intriguing to think in terms of the maximum whether we are dealing with efficiency, speed, visibility or other factors. The maximum visibility of an object is not actually reached until the object is of very large size. But as size increases to very large sizes, there are obviously other aspects to be considered. For example, 24-point type on this page would actually handicap an adult reader with normal vision. Both 24-point and 18-point type are used for sight-saving pupils with very defective vision because other considerations are outweighed by the necessity for large type-size if these partial-sighted children are to read with a reasonable degree of certainty. However, from a practical viewpoint of critical seeing there are good reasons for considering a relative visibility (RV) of 20 a practical maximum. There are also good reasons for beginning the scale of Percent of Maximum Visibility at RV = 1.9 instead of at RV = 1. All these matters are adequately discussed elsewhere.[1] In Fig. 60 our rational scale of Relative Visibility is compared with our empirical scale of Percent of Maximum Visibility.[25]

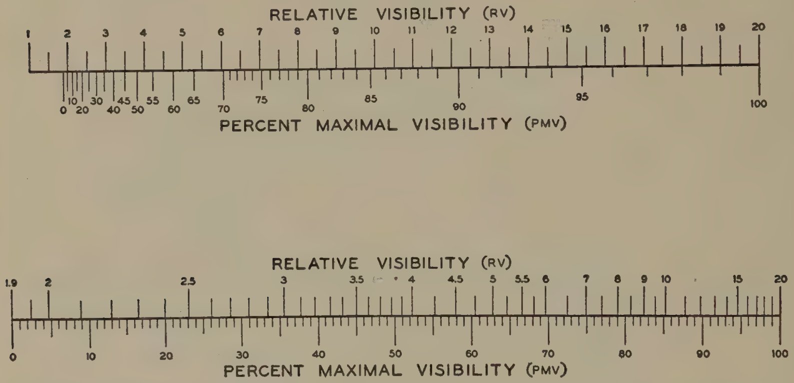


FIG. 60.—Showing the relationship of relative visibility or RV values to the percent of maximum visibility according to the arbitrary limits of our scale of relative visibility.

With the foregoing brief explanation, Table X is presented, in which various factors are summarized and compared. In the first column are the type-sizes (Bodoni Book) which, when illuminated to a level of 10 footcandles are equivalent in visibility to corresponding values of RV in the second column. In the third column are the respective footcandle-levels necessary to make the various sizes of type equal to a very conservative standard of visibility, RV = 3.7, represented by 10 footcandles on 8-point type. Naturally all the printed matter is assumed to be of excellent quality with black ink on white paper. In the last column are the percentages of maximum visibility, respectively, for the values in the first three columns.

In comparing the values in Table X, it should be borne in mind that the type-sizes[1] are used merely to aid in visualizing the visibility scale of the visibility meter and also the RV values obtained with it for various objects and tasks. The footcandle scale on the visibility meter is the very conservative one in the third column of the table.

TABLE X

The Relationships of Four Ways of Expressing Relative Visibility. A Level of Illumination of 10 Footcandles Is Involved in the First Two Columns. The PMV Scale Begins at Zero for RV = 1.9.

Equivalent Type-Size ETS	Relative Visibility RV	Footcandles for Equal Visibility	Percent of Maximum Visibility PMV
3	1.15	900	..
4	1.66	140	0
5	2.16	50	11
6	2.67	25	28
7	3.18	15	39
8	3.69	10	48
10	4.71	6	60
12	5.73	4	68
14	6.74	3	74
18	8.78	2	82
24	11.83	1	89

The 900 footcandles necessary to make 3-point type equal in visibility to that of the very conservative standard is of academic interest because such a footcandle-level would make the brightness of the white paper of a printed page too high for easiest seeing. This is revealed in a later chapter. In fact, it should be emphasized that in the present chapter we have been dealing entirely with visibility, but at least in extreme cases we must take into account a result which we have termed, ease of seeing. For example, 4-point type cannot be read for long periods with the same ease as 10-point or 12-point type even though, by appropriate levels of illumination for each, their visibilities are made equal. Here we might again recall the analogy of sighting a rifle on small and large targets, respectively. The strain will be greater in reading fine print than suitably larger print even at the same see-level.

Of particular interest are the low visibilities of many common tasks under the levels of illumination which are prevalent. For example, even at the footcandle-levels indicated in Fig. 59, the visibilities of the tasks remain relatively low. They are actually less than the standard of visibility represented by RV = 4 and illustrated in Fig. 58. Actually 10 footcandles on 8-point type produce an RV of 3.7 for normal vision at the common reading distance of 14 inches. It will be noted from Fig. 60 and Table X that the visibility of the tasks in Fig. 59 is about 50 percent of maximum visibility because their RV is only 3.7. Instead of the relatively high footcandle-levels indicated in Fig. 59, these tasks are generally performed under levels of a few footcandles. Under these conditions the visibilities correspond to those of small type-sizes and are often less than 10 percent of the maximum. From every viewpoint measurements of visibility of common objects and tasks reveal a woeful negligence and ignorance in the everyday world of seeing. Only by measurements can we learn how to use and to specify light, lighting and other aids to seeing.

VARIOUS USES AND PRECAUTIONS

The applications of the visibility meter are as widespread as seeing. We have discussed some of the simpler uses which provide results of great importance. Space does not permit going far afield into a variety of applications but a few other glimpses may be helpful. As already emphasized, this device was primarily developed for research under laboratory conditions of control. However, with due precautions the applications can be extended throughout the world of seeing.

Extraneous light from sources and areas in the visual field surrounding the object or task, if allowed to enter the windows of the visibility meter, will add to the veil of haze. This will affect the visibility measurements. Therefore, it is well to screen the visibility meter from extraneous light. However, extraneous light, if it is constant or reasonably so, does not affect the determination of relative visibilities.

It is also desirable to measure the visibility of a standard task, such as 8-point type, while making other measurements of visibility. In fact, a standard printed card has been furnished for the purpose. This makes it possible to compensate for the observer's vision and for other factors which influence the visibility measurements.

In the case of three-dimensional objects, the direction and diffusion of the light may affect their visibility very much. In fact, there are cases where a few footcandles of properly directed light will make certain three-dimensional objects as visible as they may be under a hundred footcandles, or more, of misdirected light. It is generally possible to so direct the visibility meter at the task and to protect it with a hood that the effect upon visibility of various directions of light or kinds of lighting can be determined. Sometimes it is desirable to cover everything in the visual field, excepting the object or task whose visibility is to be measured, by means of black cloth or even velvet. Usually it is not difficult to exercise the proper precautions. However, inconsistencies arising from misuse and lack of proper precaution have been unjustly blamed upon the visibility meter.

One criticism of the visibility meter is that it does not reveal the effect of glare upon visibility. Being held before the eyes it does shield the eyes from glaring light-sources or specularly-reflected images. We have long been conscious of a need for measuring visibility, when preventable glare is present, by some means which does not shield the eyes. However, a long tedious research in which we sought to make a filter which would properly appraise the effect of glare upon visibility revealed that the present photographic gradients do this job fairly well under certain conditions.[26]

Therefore, the visibility meter not only provides a means of measuring the visibility of objects on the highway but also accounts fairly well for the part that glare from light-sources plays in reducing visibility. However, its most extensive uses do not necessarily involve preventable glare.

Aside from these and many other special applications, the visibility meter provides an excellent means of measuring visibility under controlled conditions and also a foundation of knowledge upon which to specify light and lighting for specific tasks. Any tool dealing with a complexity, such as seeing, must be used with understanding and suitable precautions.

Now with a better understanding of visibility measurements and of the meaning of visibility the reader might turn to Fig. 28. The measurements of visibility of printed matter, in three positions with respect to the line of vision, are very easily made. As a consequence one quickly learns from emphatic data what the inclination of this page does, in effect, to the size and visibility of the type and how the reduced visibility can be compensated by definite increases in the level of illumination.

The reader might also turn back to Fig. 33 and review the factors and quantitative values in detail. It will be noted that the RV values for the first pair are less than 4. We now know that these visibilities represent a fairly low standard of visibility or see-level. The RV values for the second pair finally attain almost the maximum visibility, according to our RV scale. However, an RV of 19 or 20 and a PMV of 72 or 99 is attained for the right-hand member of the right-hand pair only by providing 1000 and 3750 footcandles, respectively. Sometimes, very high visibility is needed for quick and certain seeing.

Before me is a distinctive blue letterhead of a large company. The same typist typed a few lines on the blue paper and also on a white paper. Under a level of illumination of 10 footcandles the typewritten lines on the blue and white papers have an RV of 2.5 and 5, respectively. The equivalent type-sizes are 5.6 points and 10.6 points, respectively. If the recipients of these letters on blue paper have only 10 footcandles available, they must read the equivalent—in visibility—of less than 6-point type. It requires 60 footcandles to make the typewritten material on the blue paper have the same visibility as that on the white paper has under 10 footcandles. The visibility meter makes such measurements, conclusions and specifications possible. They can be accomplished by no other available means.

If anyone has watched the matrices of a type-setting machine fall into place before the eyes of the operator, perhaps he has noted that the identifying letters are of very low visibility. In such a case they were found to have an RV of only 1.1. Obviously this is at the threshold of visibility at the normal reading distance. The operator had to lean close and strain his eyes to see them. When these indented identifying letters were clean and processed with white lacquer their visibility rose to 4.6. Now they are visible to normal eyes at a normal distance with a factor of safety of 4 in size equivalent (see Fig. 55). Their former visibility was about equivalent to 3-point type under 10 footcandles. Now their visibility is greater than 9-point type under 10 footcandles. Old eyes with a visual efficiency of 50 percent can see the latter but a visual efficiency of 100 percent—average normal vision—is necessary if the original matrices are to be recognizable at the normal distance of 14 inches.

These are only glimpses of countless examples of the need for measuring visibility and the value of such measurements. We know very little about anything until we have made measurements. These are at once the basis of science and much of its structure. Visibility is the overwhelmingly important aspect of seeing. Therefore, its measurement is equally important in the science of seeing and to the seeing specialist whether he deals with light or any other factor in seeing.

CHAPTER XIII

Ease of Seeing

Visibility is associated with objects to be seen or with visual tasks to be performed. Obviously our visual ability is always involved, but our control of visibility depends entirely upon external factors. With the exception of eyeglasses or other optical devices, such as magnifying glasses, microscopes and telescopes, the factors by means of which we can control visibility are associated directly with the object or task, its background and its surroundings. In preceding chapters the relationships of the fundamental factors have been discussed and illustrated for the limiting condition of threshold visibility or barely seeing. In addition to these fundamentals we have discussed supra-threshold visibility and have considered various possible standards of visibility or see-levels. However, there is another aspect of seeing which we have termed *ease of seeing*. This must be the criterion and guide in establishing see-levels and in appraising seeing conditions.

Fig. 61 may aid in visualizing the relation of knowledge to various practices. It emphasizes one of the basic responsibilities of the science of seeing which is to establish some means of determining the conditions necessary for easy, easier and easiest seeing. To do this the relatively new concept—ease of seeing—must be considered along with visibility. We used to speak of this new concept as see-ability but it was too often confused with visibility. It does not directly suggest ease or difficulty, or that seeing is work that we do just as any other human activity. It is natural to think of the visibility of these printed lines, or of any detail on this page, as something apart from us. However, while performing any task of seeing we are *human seeing-machines*. As such we are concerned with *ease of seeing*. This involves much more than see-ability or our ability to see.

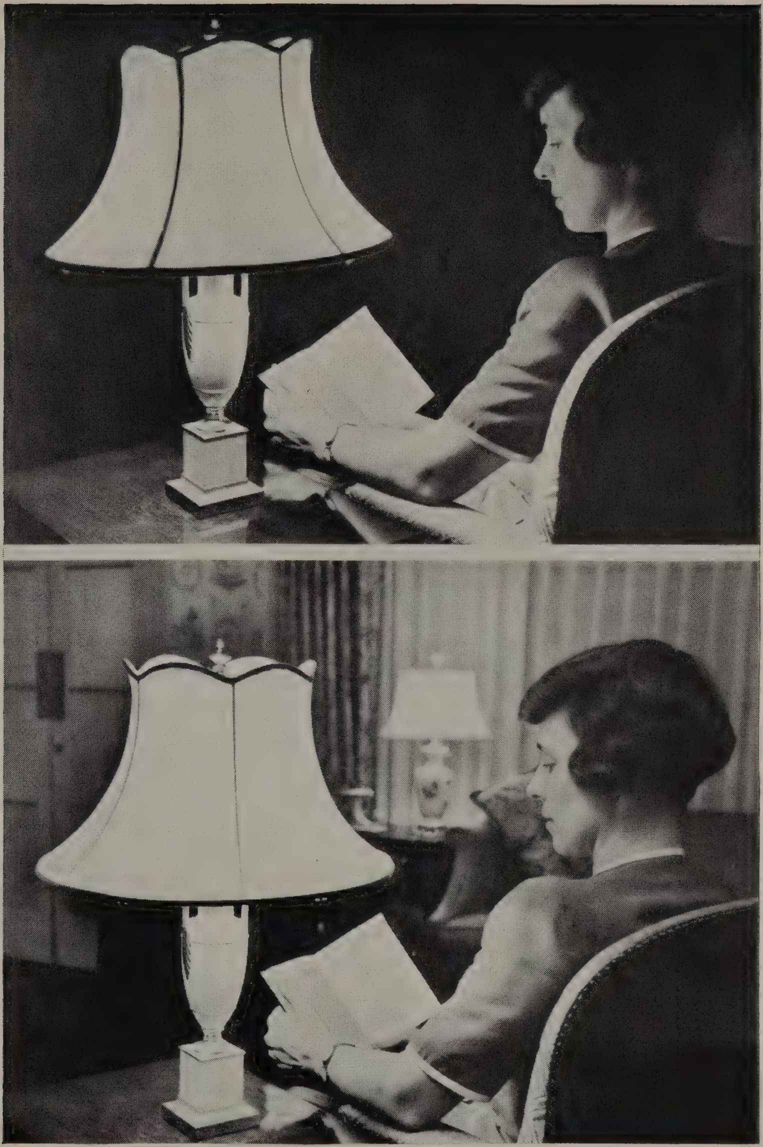


Plate XIII.—Ease of seeing is determined by the visibility of the visual task, such as reading, and by other factors such as the brightness-ratio between the task and its surroundings. Dark surroundings cause unnecessary strain, tenseness, annoyance and fatigue.

Fig. 61 applies to any controllable aid to seeing. For example, let us consider size of type. Under ordinary seeing conditions, persons possessing average normal vision can barely read 3-point type. Therefore, if that size of type were used to print this page we would be making a minimum utilization of this factor. This condition is represented by the horizontal arrow in Fig. 61. Immediately, the question arises, What is the proper type-size for easiest seeing? This depends upon various other factors, but for educated adults the optimum type-size is apparently somewhere in the neighborhood of 12-point or 14-point type. Whatever it is, the vertical pointer represents the maximum or optimum utilization of the factor of type-size.

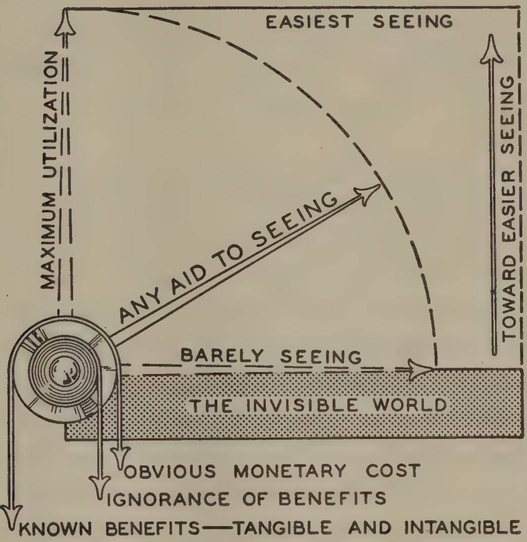


FIG. 61.—A schematic diagram which illustrates the degree of usage of any aid to seeing—type-size, eyeglasses, footcandles, etc. The maximum contribution of any of these or other aids to seeing is not easily determined. As knowledge of the known benefits is obtained and disseminated, the retarding effects of monetary cost and of ignorance of benefits are diminished. See Fig. 4.

The diagonal pointer in Fig. 61 may be set at any position to represent common practice. For example, the body-type of newspapers averages slightly larger than 7-point. Thus in this case, the utilization of type-size as a controlled aid to seeing has progressed considerably above the minimum but it is still appreciably below the maximum. Actually for the short line-lengths of newspaper columns the size of type for maximum ease of seeing (reading) may actually be 10-point or not much larger. As indicated in Fig. 4, books for adults are commonly printed in sizes from 10-point to 12-point. Thus in this case the diagonal pointer in Fig. 61 would be more nearly vertical. Books for children are printed in still larger types, but probably the best type-size for these less adept readers is larger than that for educated adults.

If we examine the diagrammatic mechanism of Fig. 61 more closely we see conflicting forces at the pulley. The result of this conflict determines practice, illustrated by the diagonal position of the pointer. Economic factors, combined into obvious monetary cost, tend to resist a better utilization of type-size. Research reveals benefits of easier seeing and, therefore, of larger type-size than those which may be in general use. Publishers and readers of printed matter may be ignorant of some of the benefits revealed by the science of seeing. The resultant of such forces as illustrated in Fig. 61 determines typographical practice. However, as knowledge of benefits has increased, type-size has generally increased. The ideal goal is the optimum sizes for easiest seeing.

Inasmuch as light is an essential, universal and highly controllable aid in seeing, we may well ask, What is the best level of illumination for reading these pages for long periods? If that question is answered even approximately we immediately have some links connecting all other tasks to this task of reading. The connecting links are levels of visibility, of brightness and of illumination. Turning again to Fig. 61, the horizontal pointer represents just enough light for barely seeing to perform this task of reading, for example. However, the science of seeing must reveal what the level of illumination must be for maximum ease of reading these pages and, of course, the maximum levels of illumination for other tasks.

Anticipating some of the results presented later in this chapter it may be said that the levels of illumination and of brightness for maximum ease of seeing (reading these pages) are, respectively, above 100 footcandles and 100 footlamberts. Most reading and most other visual tasks are performed under a few footcandles at the present time. Therefore, the position of the diagonal pointer in Fig. 61 in representing general utilization of level of illumination is much closer to the minimum than to the maximum utilization. This is a part of the reasoning upon which Fig. 4 is based.

When one has a clear concept of ease of seeing, various questions arise for every prolonged task of critical seeing. All these combine into one question, What are the conditions for easiest seeing? or How good should seeing conditions be? The answers to questions involving ease of seeing are to be found only in the realm of physiological—actually psychophysiological—effects of seeing. Without such knowledge we can eliminate obviously poor seeing conditions but we cannot be certain, by a long way, of seeing conditions necessary for easiest seeing. Without such knowledge we are generally dominated by narrow economics and too often are "penny wise and pound foolish."

PHYSIOLOGICAL EFFECTS OF SEEING

Headaches, dizziness, nausea and indigestion are often recognized by eyesight specialists as resulting from undue eyestrain. These may be accompanied by inflammation, tearing and pains in the region of the eyes. When any of these effects and disorders are diagnosed as resulting from eyestrain, some recognized causes are defective vision, incorrect eyeglasses, glare from light-sources, inadequate light, generally poor seeing conditions and misuse and abuse of the eyes. In such cases, both cause and effect are generally quite obvious. These are representative of extreme external conditions and internal effects. They are so obvious that corrective measures generally should be just as obvious to the specialist.

In invading the realm of ease of seeing, we must be concerned with less conspicuous and even unobvious causes and effects. We must be conscious of the interminable hours of critical seeing that occupy much of our days, years and lifetime. Naturally we must be concerned with strain and fatigue, not only of the eyes, but of the entire human being. This is the result of the concept that seeing is more than activity of the eyes and visual sense. Seeing involves energy expended in the muscular, neural and mental systems of the entire human being. This is another glimpse of our reason for distinguishing between vision and seeing. One encompasses the eyes and the entire visual sense, but the other encompasses these and the entire human being.

During several decades of research we have also invaded the internal realm of effects of seeing by studies of such effects as fatigue of the external eye-muscles of convergence, fatigue of the muscle which controls the pupil of the eye, tenseness or nervous muscular tension pervading the entire human being and manifested at the finger tips, the pulse or heart-rate, and the rate of involuntary blinking. These cover an extensive range throughout the muscular, neural and even mental realms.

For the most part these effects are unobvious and in our researches the causes were, for the most part, mild or subtle. Excepting when intentionally studying glare, the seeing conditions were the best that we could devise for the levels of illumination which varied from 1 to 100 footcandles in most cases.

We eliminated defective or subnormal vision as a possible influence by using subjects possessing average normal vision. The subjects were healthy educated adults less than 35 years old and various groups of subjects generally averaged between 25 to 30 years of age. Thus, in addition to eliminating the effects of subnormal vision, we avoided the possible effects of ill health, old age or extreme youth.

We chose reading as the visual task because it is controllable, describable and readily reproducible. Unless otherwise stated, the reading matter consisted of fairly large type—10-point to 12-point—printed with non-glossy black ink on non-glossy white paper and of line-lengths commonly used in books. Such a task is much easier than many tasks of the everyday world of seeing. Each subject read alone in a quiet comfortable room and all recording apparatus was in an adjoining room.

From the foregoing it is seen that our criteria and techniques were put to severe tests. The details and results of continuous researches, extending over many years, have been extensively published in scientific journals and all have been more adequately summarized elsewhere.[1] Here only essential highlights are greatly condensed from a practical viewpoint. However, the difficulties, the great amounts of time involved, the intricate apparatus and the meticulous care necessary in all phases of research with human beings cannot be over-emphasized. Such researches must be performed in laboratories adequately equipped with facilities, ingenuity, experience, skill and time if the results are to be worth while. These are matters which must be properly appraised before accepting the results of any researches dealing with human subjects, mild causes and subtle effects.

Some of the results are presented in Fig. 62 for three levels of illumination of the reading matter—1, 10 and 100 footcandles.[27] For the sake of comparison, relative visual acuities for black objects on a white background are included. The effects of illumination upon contrast-sensitivity are also shown for a specific case of our parallel-bar test-object, 1.8 minutes in visual size and of low brightness-contrasts, 7 per cent to 32 percent, with its background.

FATIGUE OF EYE-MUSCLES

Each eye has six external (extrinsic) muscles which turn and converge the eyes so that they perform as a team. They are analogous to the harness of a team of horses. These muscles must converge the line of sight of each eye so that the two lines converge in a point of fixation upon the object to be seen. In reading these lines of print these eye-muscles not only converge the lines of sight accurately, but also move this point of fixation carefully along each line in a series of steps. If one will visualize this process in detail, he will likely conclude that fine print should

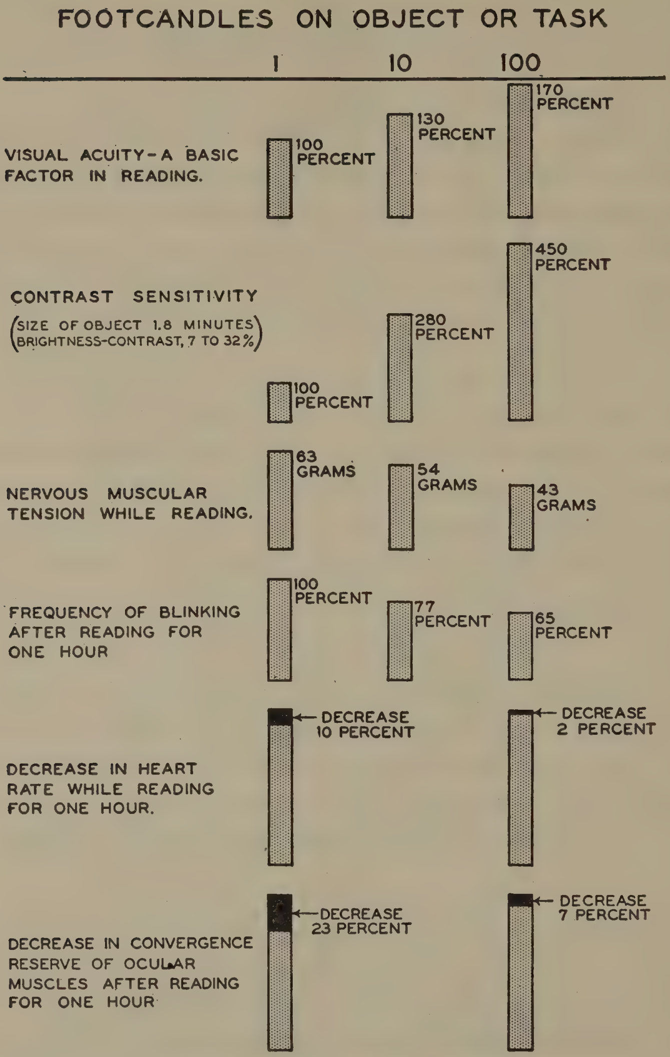


FIG. 62.—Illustrating the results of some extensive researches, reported in detail elsewhere, of the beneficial effects of increasing the level of illumination upon the visual task from 1 to 10 to 100 footcandles. The reading matter was representative of good typography.

cause more strain on these muscles than larger print. Imagine our eye-muscles moving this point of fixation carefully along ten feet of printed lines in reading a page or nearly a mile in a day's reading! Imagine traveling half way around the world in a lifetime of critical seeing!

Pursuing this reasoning and visualization further, one may wonder how the strain on these eye-muscles, and eventually their fatigue, may be affected by increasing the level of illumination for the same reading matter. Inasmuch as it is possible to test the strength of various muscles before and after they have done a certain amount of work, any effect of higher visibility obtained by increasing the illumination or brightness-level of the printed matter can be ascertained. Obviously by increasing the brightness of this page the visibility of the printed matter is increased, but what is the effect of higher brightness-levels upon ease of seeing?

As indicated in Fig. 62, it was found that the muscles of convergence were decisively less fatigued after reading a book of excellent typography for an hour under 100 footcandles than after reading an hour under one footcandle. Expressed scientifically, the "convergence reserve" decreased three times as much during an hour's reading under one footcandle as it did under 100 footcandles. Naturally all factors of the reading matter and of the seeing conditions were constant excepting for the two different levels of illumination of the printed pages.[28]

A similar result was obtained for a group of skilled key-punching operators in a statistical department.[6] The fatigue of their eye-muscles of convergence was determined daily throughout six consecutive weeks with 10 and 60 footcandles, respectively, on the cards which they had to read while performing the key-punching operation. The 10 footcandles were obtained from general illumination by a semi-indirect lighting system. To this, 50 footcandles were additionally supplied to the task by excellent supplementary illumination from a well-shaded and diffused light-source on each machine. The decrease in "convergence reserve" was four times greater after a day's work under 10 footcandles than it was under 100 footcandles.

THE SIZE OF THE PUPIL

The size of the pupil is controlled by a muscle which, when paralyzed by an appropriate drug, allows the iris to open to full size. As this muscle becomes fatigued either directly or possibly through a general bodily fatigue, the size of the pupil becomes correspondingly larger for a given brightness condition.

Careful measurements of pupil size [29] made at the beginning and end of the day's work revealed that the pupil size is greater at the end of the day. This increase in the size of the pupil was greater as the week progressed. After the holiday at the end of the week it returned to "normal." Tests of a group of office workers for four consecutive weeks revealed an average increase of 15 percent in the area of the pupil during the day's work.[30]

The pupil size is affected by many factors and, therefore, it is not a very alluring criterion for practical use. However, the foregoing results reveal a definite effect of fatigue from office work which consisted largely of seeing. As indicated by the progressively larger pupil from day to day, 16 hours overnight was not enough for complete recuperation. Thus we see the prolonged and far-reaching effects of seeing.

TENSENESS OR NERVOUS MUSCULAR TENSION

Tenseness and fatigue are common experiences, but when they subtly arise from subtle causes they may escape our notice. However, it is the task of research to discover unobvious hidden effects. When we first began to theorize about seeing as an activity of the entire human being, we were encouraged by observations of the effects of extreme conditions. While driving an automobile in traffic, when seeing carries great responsibility, or in a fog when seeing is difficult, we are often conscious of strain, tenseness and eventually fatigue. Holding the sights of a rifle on a small target makes us more tense than when the target is large.

Reading under extremely adverse conditions quickly results in an obvious tenseness. From such experiences we were encouraged to develop sensitive apparatus in order to ascertain whether we could measure the difference in tenseness—nervous muscular tension—while reading printed matter of excellent typography of different visibilities or at different see-levels due to different levels of illumination. Otherwise the seeing conditions were constant and as good as our experience could make them.

We put our theorizing to the severest test by choosing as the visual task a book printed in 12-point type on excellent non-glossy paper. Each subject read alone for 30-minute periods during which the pressure unconsciously exerted by his finger tips on a large flat button was continuously and automatically recorded. With the arms resting naturally, it was found that tenseness manifested itself by a tendency to crook the fingers. Thus the pressure on the large button increased with tenseness, depressing a delicate spring and making one of ten electrical contacts which recorded the degree of pressure. The tenseness was thereby automatically recorded in grams of pressure.

The average results for 14 adults are presented in Fig. 62. Each subject read for eight different periods under each of three levels of illumination—1, 10 and 100 footcandles—without any preventable glare and with surroundings of a suitable brightness. Thus more than 300 reading-periods were involved, exclusive of the usual preliminary shakedown periods. The original data for each subject reveal in every case a decisive decrease in tenseness or nervous muscular tension, with increase in level of illumination.[31] This was the first convincing evidence that the effects of seeing, under fairly good seeing conditions, are widespread throughout the human being. It will be noted that the typography of the book was excellent and approached the optimum for educated adults. The increases in visibility of the reading matter were due entirely to increases in the level of illumination for the reading matter was the same throughout the entire research.

The results indicate that 100 footcandles on a white page of printed matter are less than the optimum level for easiest reading.

In other words, they indicate that a brightness of 100 footlamberts for a prolonged task of critical seeing is decidedly better than lower brightnesses from the viewpoint of tenseness or ease of seeing. Other results indicate that the optimum brightness for easiest reading and, by extension, for easiest seeing may be in the neighborhood of 300 footlamberts. This is of the order of magnitude of the brightness of a green grass lawn and similar areas outdoors in the daytime.

This same criterion was used to study the effects of glare.[32] An inside-frosted tungsten-filament lamp was hung 20 degrees above the line of vision. It was at such a distance that the illumination at the eyes of the reader was 5 footcandles and the illumination on the reading matter was 5 footcandles. The indicated tenseness was twice as great when the glare was present than when the glare-source was shaded from the eyes. Incidentally, the tenseness was about the same while reading under one footcandle without the glare as it was while reading under 5 footcandles with the glare present.[6] This gives some idea of the penalties of glare from the viewpoint of ease of seeing.

THE HEART-RATE

The heart responds to numerous physiological and psychological factors. Therefore, one might expect the heart-rate, or the number of beats per minute, to change with the degree of tenseness resulting from performing the task of reading under different levels of illumination. Seven healthy young male adults, averaging about 26 years of age, were used as subjects and their heart-beats were recorded electrically and automatically. A book of excellent typography, well printed in 10-point type on non-glossy paper was read under two levels of illumination—1 and 100 footcandles. Each subject completed 20 one-hour reading periods. For the seven subjects, tested individually once a week over a period of many weeks, a total of 140 hours of reading was involved. During the actual tests 600,000 heart-beats were electrically recorded.

While reading the relatively large print under one footcandle, the heart-rate steadily decreased throughout the one-hour period. The average "normal" heart-rate of the subjects was about 76 beats per minute. During the one-hour reading period, the average total decrease in heart-rate was about 8 beats per minute or 10 percent, as illustrated in Fig. 62. Incidentally, it required about 30 minutes for the heart-rate to return to "normal" after an hour's reading at the one-footcandle level.[33]

During an hour's reading under the 100-footcandle level the heart-rate remained almost normal. The average total decrease was less than 2 beats or about 2 percent.

It is an interesting fact that the heart-rate appears to remain about normal while reading printed matter of excellent typography, under a level of 100 footcandles. Owing to the technique employed, it was not possible to have an intermediate level such as 10 footcandles. However, the heart-rate declined markedly during the hour's reading under one footcandle and we have the results of many other researches for these and intermediate footcandle-levels. The implications of these results are many and the results are consistent with those of tenseness, for tenseness slows the heart-rate. However, from the viewpoint of ease of seeing the 100-footcandle level or 100-footlambert level appears to be desirable from the viewpoint of "normal" heart-rate.

RATE OF INVOLUNTARY BLINKING

The wink is a voluntary act but the blink is an involuntary reflex. Although the blink tends to keep the eyeball moist and clean, it has a deeper significance. For years a conviction has grown among physiologists that the blink is a relief mechanism, something like a miniature safety valve which momentarily relieves strain. It had even been suggested that studies of the blink-rate might yield useful results. However, no systematic series of researches had been performed to ascertain the practicability of the blink-rate as a criterion of ease of seeing. As a consequence we began about a decade ago a series of systematic researches which yielded many useful data, some of which are presented herewith. All the data combined have established the rate of involuntary blinking as a sensitive criterion of ease of seeing, provided representative groups of subjects are used under carefully controlled conditions.

The blink-rates of various individuals differ widely and are different for different tasks. One person may blink several times faster than another person under identical conditions. Furthermore, the blink-rate of an individual depends upon what he is doing. However, these differences are of no consequence when a specific task, such as reading, is chosen and the same subjects are used for studying the relative effects of two or more conditions.

The results of a decade of researches, which are very briefly discussed herewith, have been published in appropriate journals[34] and summarized in technical books.[1] They may be consulted by those who wish to examine the data critically. However, it should be emphasized that we were interested primarily in revealing trends. For example, our objective was to ascertain which of two or more type-sizes, levels of illumination, seeing conditions, etc. is best from the viewpoint of ease of seeing. Some idea of the magnitude of the work, upon which our conclusions are founded, may be gained from the following summary:

A total of 40 researches have been prosecuted with the rate of blinking, involving 81 different subjects averaging less than thirty years of age and possessing average normal vision, or in some cases corrected to normal by means of eyeglasses of relatively slight corrections. From other researches involving vision and seeing the subjects were known to be typical.

The total number of actual reading periods, during which blinks were actually counted, was about 5000.

The total number of blinks actually counted was about 150,000. Inasmuch as the average blink-rate was about 6 blinks per minute while reading, blinks were counted during a total of about 25,000 minutes or a total of more than 400 hours. The blinks were always counted by an observer outside the visual field of the subjects, and quite generally unbeknown to the subjects.

The rate of involuntary blinking was alluring as a possible criterion of ease of seeing for two important primary reasons. First, physiologists had generally come to the conclusion that the blink is a relief mechanism and, therefore, is associated with strain and fatigue. Therefore, it appeared reasonable that it was associated with ease of seeing. Second, the blink is a reflex or involuntary act and subjects, while absorbed in the task of reading, do not exercise voluntary control over their rate of involuntary blinking. This is not true of speed of reading, for example. The attitude or interest of the reader might affect speed of reading materially. Incidentally, in our first series of researches with the blink-rate, the subjects did not know we were interested in blinks, but apparently this made no difference. In none of the researches were the subjects aware that their blinks were being counted.

We began our investigation of the possibilities of the rate of involuntary blinking as a criterion of ease of seeing by prosecuting certain "axiomatic" researches with sufficient subjects and data to draw reliable conclusions. We reasoned that there are certain axioms or self-evident facts pertaining to strain and fatigue as follows:

They should increase as the period of reading increases.
They should be greater while reading 6-point type than while reading 12-point type under identical conditions.
They should be greater when subjects wear incorrect eyeglasses than when they wear correct ones.
They should be greater while reading with a glaring light-source in the visual field than when the glare was absent.

The average increase in the rate of blinking with the duration of the reading period is shown in Fig. 63 for three 5-minute periods of an hour's reading. These periods were the first 5 minutes, the last 5 minutes and an intermediate 5 minutes. The illumination of the reading matter was one footcandle and the results are the average rate of blinking for 18 typical subjects.

In Fig. 63 are also shown the average rate of blinking while reading 6-point and 12-point type under the same seeing conditions.[35] These two researches were repeated in principle many times in the course of our researches with the blink-rate and the results were always similar to those in Fig. 63. They only differ somewhat in magnitude with different groups of subjects, but we are only interested in the differences in blink-rates.

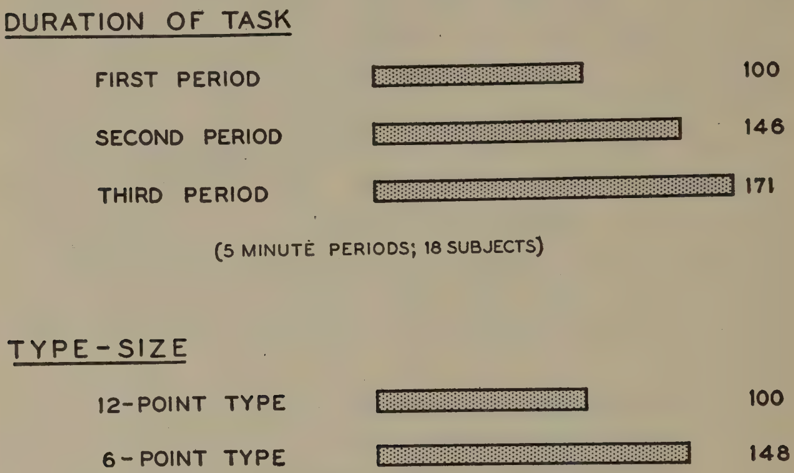


FIG. 63.—The effect of duration of the task of reading upon the rate of involuntary blinking. The lower diagram shows the effect of reading large and small type. Similar results were obtained with other groups of subjects possessing average normal vision.

The effects of slightly defective vision or of incorrect eyeglasses upon the blink-rate are shown in Fig. 64. The results of eyeglasses which were plus 0.5 diopter and minus 0.5 diopter, respectively, were compared with plano lenses or correct eyeglasses.[36] It is seen that the rate of blinking is decidedly greater for the incorrect eyeglasses or ocular errors of 0.5 diopter.[6]

The effect of glare is also shown in Fig. 64. A 50-watt inside-frosted tungsten-filament lamp was located at a distance of 3 feet in front of the reader and 20 degrees above the line of vision. The maximum brightness of the glare-source was about 60 candles per square inch and the illumination at the eyes was about 5 footcandles. With a constant illumination of 10 footcandles on the reading matter, the rate of blinking was much greater with the glare than when the glare-source was shielded from the eyes.

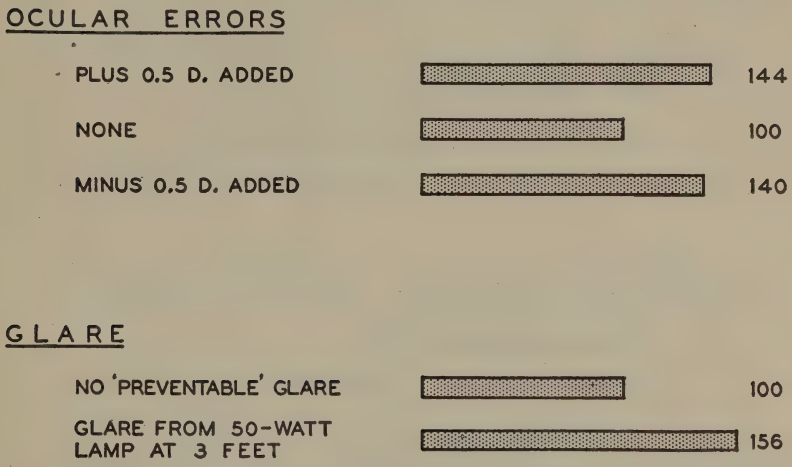


FIG. 64.—The rate of involuntary blinking while reading is greater for a small refractive error in the eyes or eyeglasses than for correct eyeglasses or no eye-defect. The lower diagram shows the effect of a moderately glaring light-source on the rate of involuntary blinking while reading.

The foregoing examples of "axiomatic" tests of the rate of blinking as a criterion of ease of seeing, and many other data, prepare us to consider the effect of illumination of the reading task. In Fig. 65 are shown the blink-rates at the end of an hour's reading under 1 and 10 footcandles compared with that at 100 footcandles. It is seen that the blink-rate is decidedly greater for the lower levels of illumination. Viewed the other way, the rate of involuntary blinking decreases as the level of illumination increases. For this group of subjects it was only 65 percent as great while reading under 100 footcandles as it was at one footcandle.

The lower half of Fig. 65 is even of more interest. During an hour's reading with the pages illuminated to a level of 100 footcandles, the average blink-rate for this particular group of subjects increased only 8 percent. At the 10-footcandle level it increased 31 percent, and with one footcandle on the reading matter it increased 72 percent.

There are quite a number of modern type-faces that are generally used and are quite acceptable. To distinguish differences among type-faces, of the same size and of no marked differences in boldness, is a severe test of any criterion of ease of seeing. In Fig. 66 the average results of 42 subjects are presented for three type-faces of the same size (10-point) and under identical seeing conditions.[35]

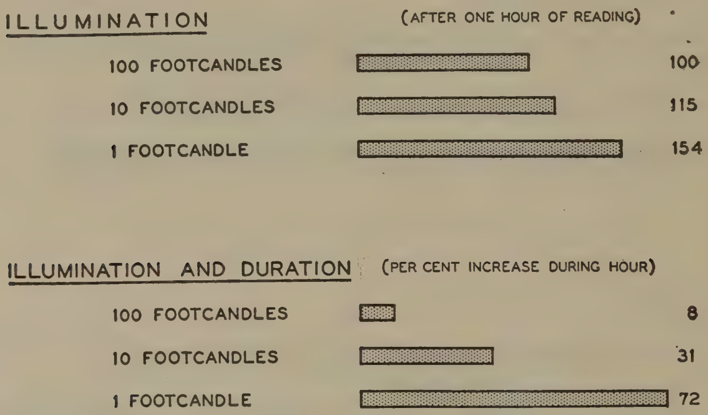


FIG. 65.—Showing the decrease in the rate of involuntary blinking while reading as the level of illumination is increased. In the lower diagram it is seen that the rate of blinking while reading increases only slightly after an hour's reading under 100 footcandles. At lower footcandle-levels the increase is decisively greater even for reading matter of excellnt printing and typography.

The lower half of Fig. 66 shows the results for the Memphis family of 10-point types which vary in boldness. The first three have the same alphabet-length and therefore are strictly comparable. The extra bold member has a longer alphabet-length and boldness is overdone from the viewpoint of readability or ease of seeing. In fact, the Memphis medium is best from the viewpoint of ease of reading, as indicated by the lower blink-rate.

It is particularly interesting in this case to compare the average results obtained from two different groups of subjects in two distinctly different researches conducted several months apart. In the first research 40 subjects were used, and 18 subjects in the second in which only the first three types of the family were read. The consistency of the results of the two tests is striking. Other duplicate researches have also revealed a decided consistency of results.[38]

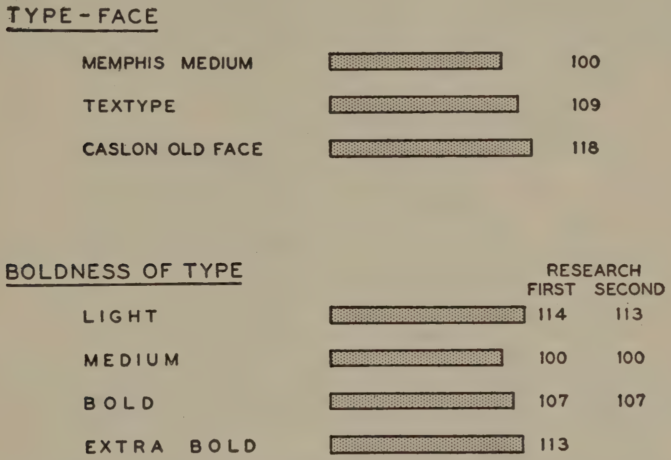


FIG. 66.—The rate of involuntary blinking has proved to be a sensitive criterion which reveals differences in readability of common type-faces of the same size. It also reveals differences in ease of reading the same type-face of different degrees of boldness.

In Fig. 67 are presented the results of leading or space between lines of type. For the same type-face (10-point Textype) and level of illumination it is seen that the rate of involuntary blinking is definitely affected by the amount of leading. Leading does not affect the visibility of reading matter, but it does affect readability or ease of seeing.[39] This is also true of the length of printed lines.[1]

Obviously one aim of the science of seeing is to relate visibility with ease of seeing. Within certain limits ease of seeing increases as visibility increases. We have seen that visibility increases with increases in level of illumination and that ease of seeing, in the case of ordinary reading matter, increases as the level of illumination increases to 100 footcandles and above. Thus we may conclude that a brightness-level of 100 footlamberts is a desirable and safe one for any task of critical seeing. Such a brightness-level is low compared with the brightness-levels of common areas outdoors. It is attainable on surfaces of low diffuse reflection-factors only by levels of illumination of 1000 foot-candles and more.

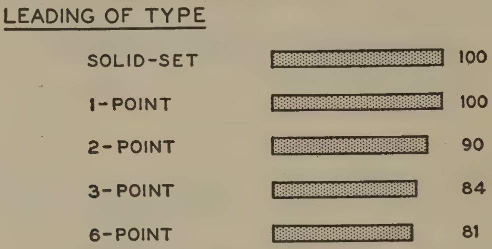


FIG. 67.—Leading, or the space between successive lines of type, does not measurably affect the visibility of the printed matter; but it affects readability, or ease of reading, as indicated by the rate of involuntary blinking while reading.

All the available data pertaining to physiological effects provide quite a substantial foundation for that aspect of seeing which we have termed, ease of seeing. We can now more clearly and safely choose a standard of visibility or see-level for any or all tasks. Such standards as 10 footcandles on 8-point type or 20 footcandles on 12-point type are certainly safe and conservative from the viewpoint of ease of seeing. Actually, a brightness-level of 100 footlamberts is safe from this and other viewpoints. This would increase the visibility of 8-point type printed on white paper to the highest see-level illustrated in Fig. 58 for persons with normal vision.

OTHER EFFECTS OF EASIER SEEING

There are other indications of other favorable effects of easier seeing. Many opportunities for statistical studies are available to eyesight specialists, production managers, safety engineers and others, but considering the importance of seeing in our everyday world, reliable quantitative data are relatively meager.

Many years ago impressive results of the increase in nearsightedness with school age were published in Sweden. It was found that this increase was more rapid in classical schools than in technical schools. Furthermore, it was found that as seeing was made easier by several means, including the abandonment of Old Gothic type and the installation of better lighting, the rate of increase of nearsightedness was measurably slowed.[4]

In a research in the mail sorting rooms of U. S. post offices many years ago it was found that the average visual acuity of mail sorters—as measured under standard conditions—actually improved in the course of a month or more under a higher level of illumination.[40] Unfortunately the highest level of illumination used in the experiments was only slightly above 10 footcandles. The average was less than 5 footcandles. Even 20 years ago it seemed incredible that such low levels of illumination were considered adequate for tests of mail-sorting in which mail-sorters of middle age had to read all kinds of addresses in script and through the windows of envelopes. However, at that time "production"—the number of pieces of mail sorted per hour—was considered by nearly everyone concerned to be an appropriate measure of the adequacy of illumination. This assumption has long since been shown to be inadequate from the viewpoints of ease of seeing or of the penalties exacted of the worker by poor seeing conditions.

If the conservation of eyesight and of other human resources were a movement of adequately broad scope, far more concern would be exercised over the effect of seeing conditions upon eyesight, accidents, health and human welfare in general. For example, the eyesight specialist who found that 78 percent of the garment workers in a large factory had defective vision, would not accept this as inevitable.[2] With the cooperation of a lighting specialist—better still, a seeing specialist—the seeing conditions would be studied and doubtless they would be improved. Then as time passed, adequate statistics pertaining to eye-defects might reveal an actual decrease in percentage and magnitude.

Some results of better seeing conditions are discussed later in connection with production and safety. They involve estimates by employers of eyestrain and morale which indirectly affect accuracy, safety and production. However, the fallacy in most of these estimates is that production and spoilage in the work-world are adequate criteria of ease of seeing or of the penalties paid by human seeing-machines. Emphatically they are not.

Before me lies a letter which epitomizes the poor seeing conditions which are prevalent in the work-world. This middle-aged woman had spent many years in the field of decoration in which she became interested in lighting. Patriotically she went to work in a well-known war-plant. After three months she resigned because of the "utterly abominable lighting which threatened to ruin my eyes." Others, young as well as middle-aged, also resigned or increased the percentage of absenteeism for the same reason. Everywhere one looks he will find little evidence of a "seeing consciousness" or of an appreciation of the importance of ease of seeing. Civilization may well be described as a half-seeing world sorely in need of seeing specialists.

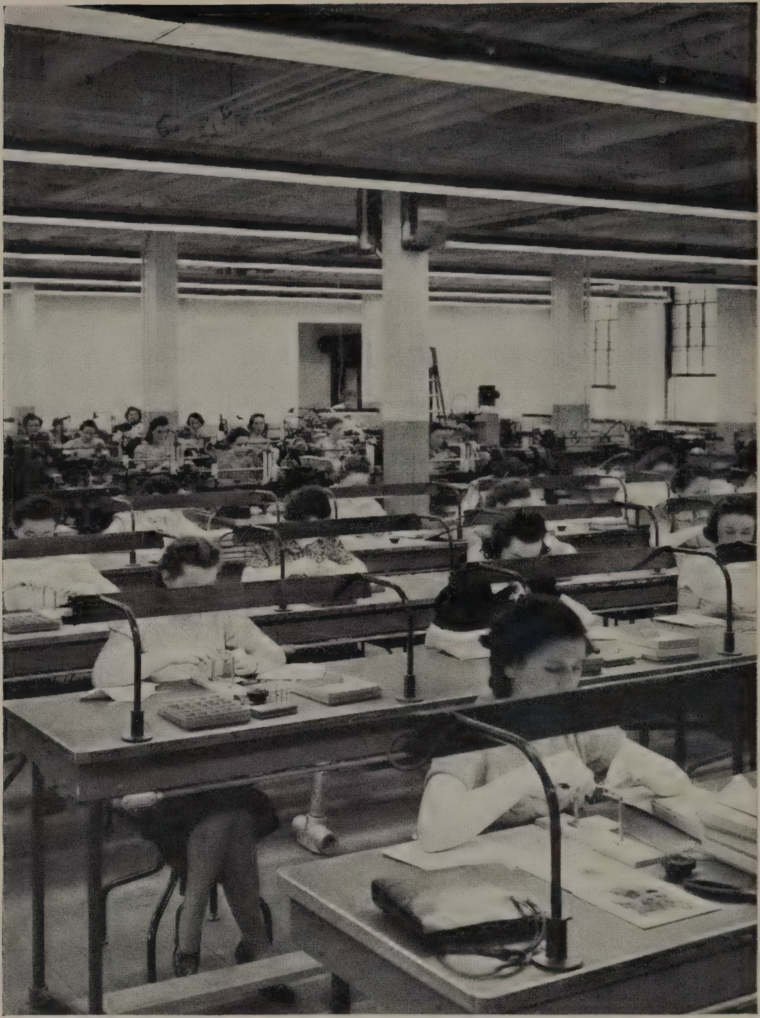


PLATE XIV.—Efficient, safe and easy seeing, wherever critical seeing is performed for long periods, are achieved by good brightness engineering. A combination of general illumination plus supplementary lighting efficiently provides high brightness-levels of the tasks for high visibility and bright surroundings for good seeing conditions. Brightness-ratios anywhere in the visual field should be as small as practicable.

CHAPTER XIV

Brightness Engineering

While performing any critical task of seeing, such as reading this page, all the brightnesses in the entire visual field contribute favorably or unfavorably to the seeing conditions. A visual task is inseparable from its environment. A dark desk-top or dark carpet may be, in effect, the immediate surroundings of this printed page. A bright area of sky seen through a window or a glaring light-source on a dark paneled wall not only reduces visibility but also affects ease of seeing to the point of obvious discomfort. The influence of any brightness diminishes as its angular distance from the line of sight increases. The entire matter of brightness in the visual field is a very complex one for it involves decoration, furnishing, taste, custom and other powerful factors. However, there is such a widespread neglect of seeing conditions that there are many opportunities for improvement without interfering too much with esthetic aspects. Even other factors will give way to some extent to progress toward easier seeing, for there is no final defense of poor seeing conditions.

Seeing conditions cannot be appraised by mere inspection unless there are gross shortcomings, such as an exceptionally critical task, an obviously low see-level, a very low level of illumination, very dark surroundings and glaring light-sources in the visual field. If a patient is in a very critical condition mere inspection by an experienced physician generally may be sufficient to determine what is the matter and what should be done. However, in most medical examinations it is necessary to search out less obvious or deeply hidden causes and effects. These involve measurements of various kinds. The physician bases his diagnosis and remedies on the foundation of science. So it must be with seeing.

A diagnosis of visibility and seeing conditions involves

1. Brightness-levels of the task and the immediate and the entire surroundings.
2. Brightness-contrast between critical details and their background.
3. Brightness-ratio of the surroundings and the task.
4. Brightnesses and brightness-ratios in the entire visual field.
5. Integrated effect of multiple glare-sources and of extended areas of relatively high brightness.

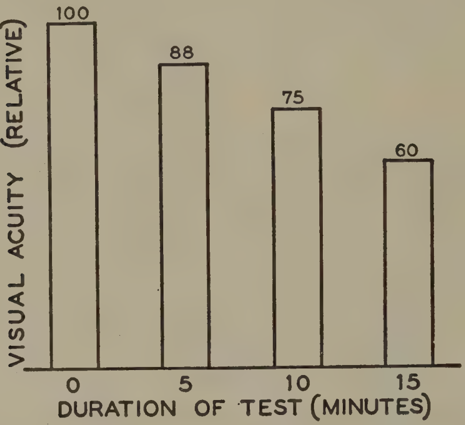


FIG. 68.—Glare from a large area of sky may not be obviously glaring when performing casual seeing but it becomes intensely so when performing a critical task of seeing. In this case the strain was so great that the subjects became extremely tense, strained and nervous in the course of 20 minutes. Visual acuity decreased as indicated. Seeing conditions cannot be adequately judged by casual observation.

High visibility, ease of seeing and good seeing conditions are the results of sound brightness engineering. However, it should be emphasized that the seeing conditions are far more effective when we are performing a prolonged task of critical seeing than when we are merely looking them over. For example, a large area of sky seen from the shady side of a building may appear benign. If we are merely engaged in conversation we may not even feel the need of an eye-shade. But the apparently mild glare of this expanse of sky becomes annoying if we are reading; and it can become viciously nerve-racking, painful and intolerable if we are performing a very critical task. In fact, tenseness and other physiological effects are extremely obvious to the initiated.

The overall effect of a bright area of sky manifests itself in a rapid decrease in visual acuity as shown in Fig. 68. The test of visual acuity required the subjects to vary the size of the test-object until they could just recognize the critical detail and to continue making these settings as rapidly as possible. Visual acuity decreased rapidly as the minutes passed. Even with an apparently benign patch of sky in the field of view this task of critical seeing generally became intolerable in about 20 minutes. No demonstration better emphasizes that seeing is an activity of the entire human being and that seeing conditions must not be appraised by merely looking them over. However, the science of seeing has revealed various facts and principles which have been established by researches in which the subjects were performing prolonged critical tasks of seeing.

THE VISUAL FIELD

Inasmuch as the distribution of brightness in the visual field determines the seeing conditions, let us briefly examine the limits and importance of various regions. The angular extent of the entire visual field varies with the physiognomy, for it is limited above by the eyebrows, on one side by the nose, and below by the cheekbones. It extends horizontally about 160 degrees and vertically about 120 degrees. (See Fig. 69.)

At the center of the visual field, along the optical axis of the eye, is a small field of about one degree in extent in which we do our accurate seeing of fine detail. This corresponds to the foveal region of the retina indicated in Fig. 7. From this one-degree field the visual field extends more than 90 degrees on the temporal side of the eye. In the outer portion of the visual field we do not see objects or colors with any degree of definiteness. However, we see changes in brightness or movements in this outer or peripheral region. This is a valuable function in promoting safety.

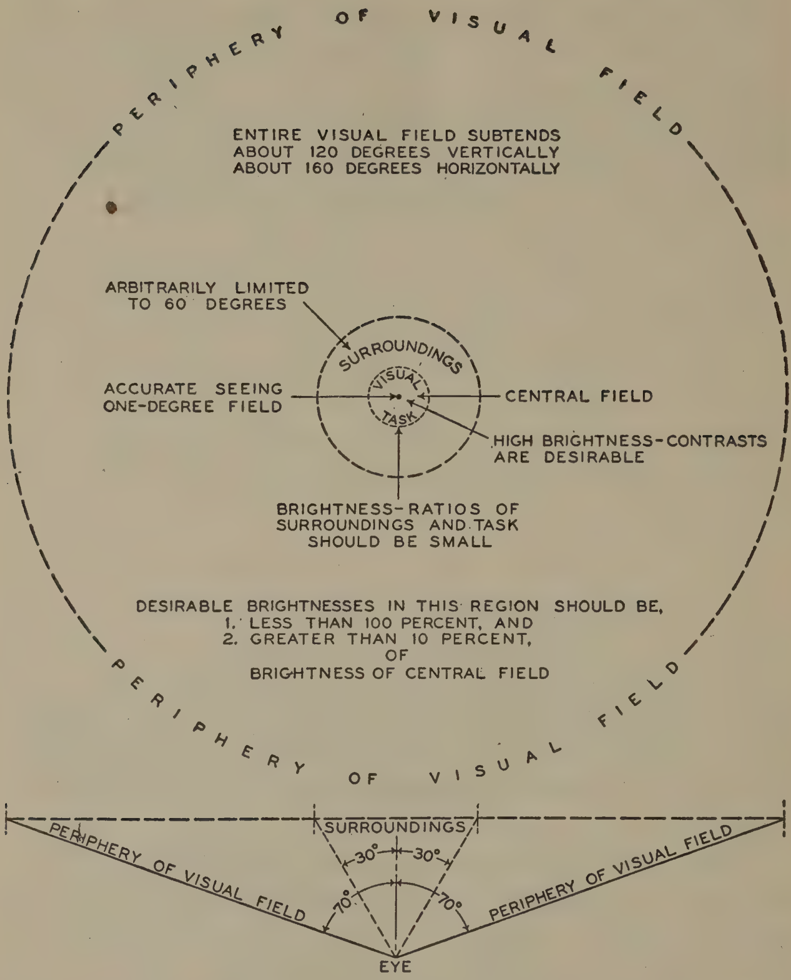

PERIPHERY OF VISUAL FIELD
ENTIRE VISUAL FIELD SUBTENDS
ABOUT 120 DEGREES VERTICALLY
ABOUT 160 DEGREES HORIZONTALLY
ARBITRARILY LIMITED
TO 60 DEGREES
SURROUNDINGS
VISUAL
TASK
ACCURATE SEEING
ONE-DEGREE FIELD
CENTRAL FIELD
HIGH BRIGHTNESS-CONTRASTS
ARE DESIRABLE
BRIGHTNESS-RATIOS OF
SURROUNDINGS AND TASK
SHOULD BE SMALL
DESIRABLE BRIGHTNESSES IN THIS REGION SHOULD BE,
1. LESS THAN 100 PERCENT, AND
2. GREATER THAN 10 PERCENT,
OF
BRIGHTNESS OF CENTRAL FIELD
PERIPHERY OF VISUAL FIELD
SURROUNDINGS
30°
30°
70°
70°
PERIPHERY OF VISUAL FIELD
PERIPHERY OF VISUAL FIELD
EYE

FIG. 69.—This diagram is an attempt to show the importance and limitations of brightness, brightness-contrasts and brightness-ratios in various parts of the visual field from the central visual task and its immediate surroundings to the periphery.

In order to break down this complex subject of brightness as it affects seeing conditions we shall use the following terms as they are defined:

The *central field* contains the visual task and its background such as this page of printed matter. The angular extent of this field varies with the visual task.

The *surroundings* of the visual task have no definite limits excepting those of the entire visual field, but there are good practical reasons for limiting this portion of the visual field. At 30 degrees from the optical axis, or line of sight, visual acuity is only one percent of its value in the tiny central one-degree field. The effect of a glare-source, and also the effect of the brightness of the surroundings, decrease as the angular distance from the line of vision increases. For such reasons and others we may think of the surroundings as occupying about 60 degrees of the central part of the visual field. A two-foot circle viewed at a distance of 21 inches subtends a solid angle of 60 degrees at the eye. A 16-inch circle viewed at a distance of 14 inches is of the same size. In fact, it is obvious that this arbitrary limit of the immediate surroundings of a visual task is a fortuitous one, inasmuch as the diameter of a circle which subtends 60 degrees at the eye is approximately equal to the distance from the eye.

The *peripheral field* may be considered to be the entire visual field excepting that small one-degree central portion along the line of sight where accurate seeing is possible. However, we shall use the term to designate the outer regions of the visual field beyond our arbitrary limit of the *surroundings* of the visual task.

Fig. 69 may aid in visualizing the various parts of the entire visual field. In connection with this diagram it is helpful to examine the brightnesses of a visual task, such as this printed page, and also the brightness of its surroundings and the brightnesses in the entire visual field. It is well to keep in mind the magnitude of the 60-degree field. This open book subtends about one-half this solid angle at the eye at the common reading-distance of 14 inches.

BRIGHTNESS-CONTRAST AND BRIGHTNESS-RATIO

We have seen in many ways that the visibility of critical details increases with the brightness-level of the visual task and with the brightness-contrast between the critical details and their background. An increase in brightness-level, up to and somewhere beyond 100 footlamberts, increases both visibility and ease of seeing. Similarly, high brightness-contrasts, up to 100 percent, are desirable in the task itself.

In order to avoid confusion it is better to use another term, brightness-ratio, when comparing the brightness of the visual task with the brightness of its surroundings. Small brightness-ratios are desirable. In other words, a large brightness-ratio between this page and its surroundings is measurably unfavorable. It reduces the sensitivity of the visual sense, and it reduces ease of seeing.

Brightness-ratios are also of importance in determining how glaring a light-source, or the bright area of any lighting equipment, may be. For example, a frosted tungsten-filament lamp may be very glaring when a dark paneled wall is the background. It is less glaring when its background is a relatively light wall. When held at a window so that a bright patch of daytime sky is its background, the glare is far less noticeable. Thus glare is related to the conspicuousness of the glare-source. This is influenced by brightness-ratio as well as the brightness, candlepower and area of the glare-source.

Obviously a practical reason for using the term, brightness-ratio, is that it is not limited to the range 0 to 100 percent as brightness-contrasts are by definition. Actually brightness-ratios are unlimited in definition as they are almost unlimited in our everyday world.

SURROUNDINGS OF THE TASK

Our ability to see small brightness-differences is an important measure of the sensitivity of our visual sense. In Fig. 70 are shown the effects of the brightness of the surroundings of the task upon the minimum perceptible brightness-difference.[41] It is seen that the sensitivity of the visual sense is greatest when the brightness of the surroundings is the same as that of the task. Furthermore, it is better to have the surroundings darker rather than brighter than the task. This is also true when we consider the psychological aspects of concentration and attention.

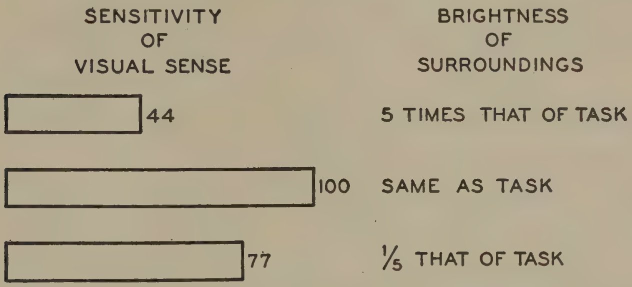


FIG. 70.—The sensitivity of the visual sense as determined by the minimum perceptible brightness-difference is greatest when the surroundings are as bright as the visual task. Surroundings should not be appreciably brighter than the task and should not be any darker than necessary.

In Fig. 71 are shown the effects of the brightness of the surroundings upon ease of seeing as indicated by the rate of involuntary blinking. It is seen that the most favorable seeing condition obtains when the task and its surroundings are of the same brightness. The blink-rate increases markedly as the brightness of the surroundings is decreased to a hundredth of the brightness of the task.[17]

The brightness of the surroundings affects the accuracy of vision.[42] With a mechanism which automatically recorded the error made by a person continually making settings of a device designed for the purpose, 400,000 settings were recorded for a group of subjects possessing normal vision. The seeing conditions were identical excepting in one case the surroundings were dark and in the other they were as bright as the task. Throughout a range of 1 to 100 footcandles on the white background of the visual task, the average error was about 12 percent greater when the surroundings were dark than when they were of the same brightness as the task. Most of the disadvantage of dark surroundings occurs when the bright central area subtends less than 30 degrees at the eye; that is, when it extends 15 degrees in every direction from the optical axis. The accuracy when the bright surrounding field subtended 60 degrees at the eye was 7 percent greater than when it was only about one-tenth as large.

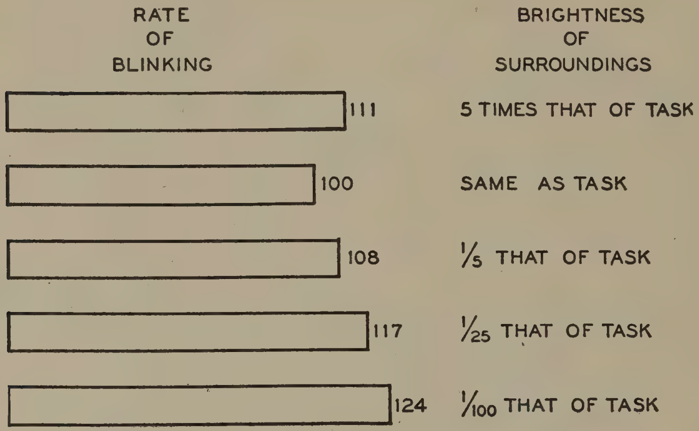


FIG. 71.—The rate of involuntary blinking while reading is lowest when the surroundings are as bright as the printed page. One of the most prevalent factors contributing to poor seeing conditions, which results in annoyance, tenseness and even discomfort, is dark surroundings.

These are a few highlights of extensive researches.[6] Other results and many experiences emphasize the desirability of low brightness-ratios of the surroundings and the task. From the data available, and allowing for necessary compromises with practicability, taste, decoration and other factors, one may conclude that, for prolonged critical seeing,

1. Brightness-ratios smaller than 1 to 5 are desirable.
2. Brightness-ratios greater than 1 to 10 should be avoided if reasonably possible.
3. Brightness-ratios of 1 to 100 should not be tolerated.

The foregoing applies to that portion of the field which we arbitrarily term surroundings and which extends about 30 degrees from the center or line of sight. A circle 16 inches in diameter and viewed at 14 inches subtends this 60-degree solid angle. From 30 degrees from the center to the outer limit of the visual field the brightness may diminish considerably without materially affecting visibility or ease of seeing. Probably brightness-ratios of 1 to 100 for the extreme outer portion of the field and the central field or task are not too great. However, smaller brightness-ratios are desirable. (See Fig. 69.)

COMMON BRIGHTNESS-RATIOS

Inasmuch as small ratios of the brightnesses of tasks and surroundings are desirable it does not matter how we express them. If the surroundings are 10 times brighter than the task, the brightness-ratio is 1 to 10 just as it would be if the task were 10 times brighter than the surroundings. Relatively rarely is the task darker than its immediate surroundings but one does encounter such cases.

Most visual tasks being brighter than their surroundings, we naturally emphasize the undesirability of dark surroundings. In this connection it may be well to emphasize again that darkness is just as definitely a sensation as brightness is. Darkness is distracting and dark surroundings can cause obvious annoyance and even obvious discomfort just as a glaring light-source does. The fact is that surroundings, whether they are only moderately darker or brighter than the visual task, may appear benign when one is merely inspecting them. Too often judgments are made in this manner. However, when one is performing a prolonged task of critical seeing the surroundings are particularly effective.

If this page is lying on a desk, the brightness-ratio is the same as the ratio of the diffuse reflection-factors of desk-top and printed page, provided there is no specular reflection. Glossy finishes are an undesirable step toward a glass desk-top which is abominable. Dark painted office furniture may have a reflection-factor as low as 6 or 7 percent. Assuming the average reflection-factor of this printed page is 75 percent it is seen that the brightness-ratio is more than 1 to 10 for the dark painted desk-top. For a desk-top of stained wood the brightness-ratio may be 1 to 5.

For years we have recommended that desk-tops have diffuse reflection-factors of 25 or 30 percent. Such a value appears to be a good compromise of various factors. With this page lying on such a desk the brightness-ratio would not be greater than 1 to 3.

For the same reasons we have recommended that the diffuse reflection-factors of walls be no less than 35 percent in any interior where critical seeing is done. Even for conversational seeing these lighter walls are desirable from several important viewpoints. Our recommendations have generally included a range in reflection-factors of walls from 35 to 50 percent. The ceiling can be white or near-white. In the home and in places of similar atmosphere the ceiling may be farther from the white as, for example, a deep cream color.

If this book is being held in the hands while reading near a portable lamp, a dark rug or carpet may be, in effect, the immediate surroundings of the task. Suppose the reflection-factor of the floor covering is 7 or 8 percent. Already we have a brightness-ratio of 1 to 10 without taking into account the different foot-candle-levels on this page and on the floor covering. The latter may be 5 times farther from the light-source than this page is. Owing to the inverse-square law, the page would then receive 25 times more light than the area of floor covering which is the surroundings of this page. Thus we have an actual brightness-ratio of 1 to 250. This is intolerably high and is a very unfavorable seeing condition. Nevertheless, it is a common condition where reading is done in the home, for example. In such cases it is a common error to blame sandy, blinking, aching eyes upon the brightness of the page. Actually the poor seeing condition is due to the darkness of the surroundings of the page. This is one of the most prevalent faults of seeing conditions and one of the most generally neglected factors.

The bright motion-picture screen amid medieval darkness is an example of poor seeing conditions demonstrated to many millions of persons daily. It is representative of the most primitive and unsatisfactory seeing conditions.[43] If looking at a motion-picture were really a task of critical seeing—which it is not—we would be more conscious of the abominably high brightness-ratios of 1 to 1000 and higher. Even so, the condition is a trying one whether we are conscious of it or not. It is easy to supply some light to the immediate surroundings without diluting the desirable contrasts in the picture itself. However, the motion-picture industry is still a victim of the illusion that you can see the picture better amid very dark surroundings. It is evident that adequate data reveal the converse to be true.

The same data and arguments apply to television and it is to be hoped that they will lead the way out of the darkness of illusion or ignorance of these facts pertaining to the influence of surroundings.

With the development of the micro-film a number of projection devices were developed for reading the enlarged image. In none of the original projection-devices, or in the cubicles in which they were to be used, was there the slightest evidence that dark surroundings are known to be undesirable. In such a case where critical seeing is to be done for long periods, the seeing conditions will be very important. The first and highly essential specification is bright surroundings and low brightness-ratios. If these factors are not properly taken care of the readers of projected micro-films are in for a bad time with very poor seeing conditions.

Many dingy dungeons—old clubs, rathskellers, paneled living rooms and libraries, writing rooms of hotels—still exist as gloomy examples of an unenlightened era in which the rudimentary principles of good seeing conditions had not yet been established. As we perpetuate them we perpetuate the era before the science of seeing. Paint is the solution in general, although if the dark stain is removed from wood paneling there will be some improvement. In such dungeons good seeing conditions by means of lighting alone are a practical impossibility. The architect or decorator responsible for them has strait-jacketed seeing and lighting conditions.[44] Thus paint and other materials of reasonably high reflection-factors are allies of lighting. Their proper use not only increases the efficiency of lighting but also increases the effectiveness of seeing and makes seeing easier.

ALTERNATING BRIGHTNESSES

Surroundings of relatively low reflection-factor often create the necessity of looking rapidly back and forth at relatively dark and bright surfaces. Office equipment as well as furniture should have higher reflection-factors than the common black of typewriters and the near-black of much office equipment. In various work-world tasks, which require the eyes to alternate rapidly between two different brightnesses, this adverse condition should be remedied if possible. Paint can readily be applied to tables and parts of machines to provide brighter surroundings.

In an extensive research it was found that the rate of blinking rapidly increased during a 15-minute period in which the eyes were obliged to see details alternately on dark and light surfaces. Actually for the first, second and third 5-minute periods the average relative blink-rates were, respectively, 100, 146 and 171 percent of what they were for the same periods when the two brightnesses were equal.[17]

The same task was used to determine the effect upon the rate of working—production of useful work—when the eyes had to rapidly see details alternately on light and dark surfaces.[45] When the two surfaces were of equal brightness the relative production-rate was taken as 100. When the brightness-ratio of the two surfaces was 1 to 10 the production-rate decreased to 97. For a brightness-ratio of 1 to 100 relative production decreased to 88—a decrease of 12 percent. Considering that the rate of performing useful work is a relatively insensitive criterion, these results are rather impressive.

GLARE—PREVENTABLE AND UNPREVENTABLE

Glare is a term applied to light entering the eyes from any visible light-source or bright area.[46] It reduces the sensitivity of the visual sense and, therefore, reduces the visibility of an object or task. Glare is also distracting and annoying often to the extent of causing extreme discomfort and even pain. Therefore, it affects ease of seeing.[32] Glare is obvious under extreme conditions such as headlamps at night on the highway, bright light-sources or lighting equipment indoors, and specularly reflected images of the sun from water or of light-sources indoors from polished metal. However, glare is always present in all seeing conditions and the problem of the seeing specialist is to eliminate preventable glare and to minimize unpreventable glare. In the latter case it is necessary to arrive at the best compromise. Here again one must rely upon the results of controlled researches of the laboratory to diagnose seeing conditions.

A bridge designer is confronted with designing a bridge to carry a certain load over a certain span. But the bridge itself has weight which is an unfavorable factor. Similarly, we illuminate this page with light, but the light reflected from this page into the eyes is, in effect, unpreventable glare. This is an unfavorable factor. However, as we increase the brightness of the page by increasing the level of illumination up to and even beyond 100 footcandles, the favorable factors increase more rapidly than the unfavorable ones. This has been proved in many ways, for the net result is increased visibility and ease of seeing up to and beyond 100 footcandles.

Similarly the light entering the eyes from the surroundings of a visual task has advantages and disadvantages. The problem for the seeing specialist is to produce seeing conditions in which the unfavorable factors have been minimized in relation to the favorable ones. For example, glaring light-sources should be screened from the eyes. However, a great expanse of bright ceiling in the case of indirect lighting is glaring if it is in the visual field. This is particularly true in large interiors. It is the brightest area in the room. This is undesirable psychologically as well as physiologically. We need bright surroundings, but not brighter than the visual tasks and their immediate surroundings.

A practical solution is found in supplying localized light to the visual tasks and their immediate surroundings. In the home this is accomplished by means of portable lamps; in offices by proper desk lamps; in libraries by table lamps or by properly placed overhead lighting units; and in industrial plants by various fixed sources. Localized light can also be supplied by light-sources at a distance and equipped with concentrating reflectors or lenses. The best combination of lighting is general illumination for the entire surroundings and localized supplementary illumination for the task and its immediate surroundings. The reflection-factors of ceiling, walls, furnishings, desk-tops and floor coverings all play a part with footcandle-levels in producing brightness-levels.

In interiors such as classrooms in schools, desk-lamps are not generally practicable. Fortunately these are not large interiors so that the general illumination can be quite satisfactory. However, compromises are just as numerous and essential in dealing with seeing conditions as in designing homes, bridges, buildings, automobiles or anything else. But we should not compromise by sacrificing fundamental principles and objectives. The ideal objective is high visibility with maximum ease of seeing.

Many years of research have established certain fundamental laws which help to appraise glare from relatively small sources.

1. The effect upon visibility depends upon the footcandle-level at the eyes due to the glare-source. Therefore, it depends directly upon the candlepower of the glare-source toward the eyes and inversely upon the square of its distance from the eyes.
2. The effect upon ease of seeing depends upon
   a. the reduction in visibility which is a matter of the footcandles at the eyes due to the glare-source; and, there-

fore, of the candlepower of the glare-source toward the observer and also of its distance from the observer.

b. the brightness of the glare-source and the brightness-ratio with its background. The brightness and area of the glare-source determine its candlepower.

3. These effects of any glare-source become less as the angular distance from the line of vision increases.
4. All effects of any glare-source decrease as the general brightness-level increases.
5. The integral effect of more than one glare-source in the visual field is the sum of the effects of each glare-source properly measured and weighted according to the angular distance from the line of vision. This also applies to an extended area of relatively high brightness such as the bright ceiling in indirect lighting. In this case the effects of each element of the extended area must be properly appraised to obtain the integral effect.

In Fig. 72 are shown the effects of glare upon the minimum or threshold size of a critical detail necessary for it to be barely visible. The glare-source was a 100-watt inside-frosted lamp located 5 degrees above the line of vision and at such a distance that the illumination at the eyes, due to the glare-source, was 5 foot-candles. Our parallel-bar test-objects of various reflection-factors, from very light gray to black, were viewed against a white background. Thus the brightness-contrast between the test-object and its background varied from 2 percent to 100 percent. The minimum sizes of the various test-objects necessary for the critical detail to be barely visible are shown for three brightness-levels of the white background—1, 10 and 100 footlamberts. The white blocks show the threshold size in each case when the glare-source was screened from the eyes. The black sections show the necessary increase in size in order for the test-object to be barely recognizable when the glare-source was not screened from the eyes.

It is seen in Fig. 72 that, particularly for objects and tasks of low contrast with their background, the glare-source enormously affected threshold size and, therefore, visual acuity and visibility. Objects which were visible without the glare became invisible when the glare was present. It is also obvious that as

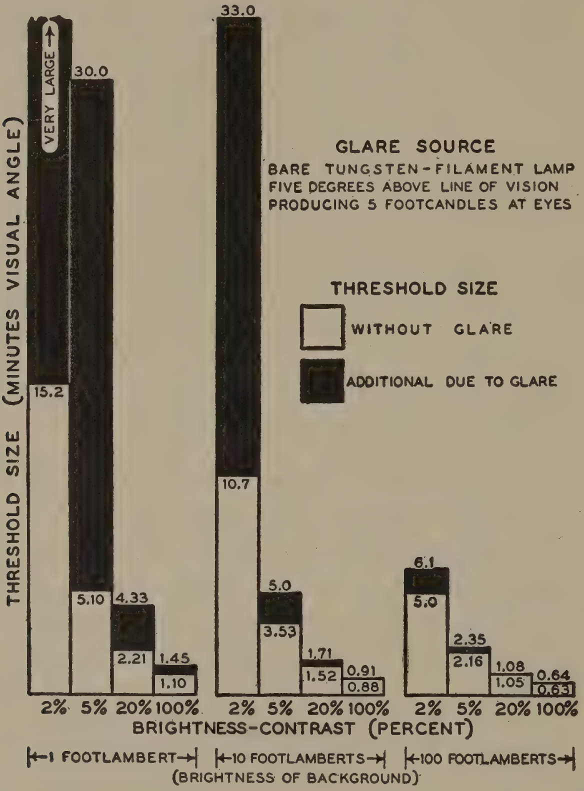


FIG. 72.—Showing the effect of a moderately glaring light-source on the threshold size of an object in order for the object to be barely visible. Without glare the threshold sizes are indicated by the white portions of the blocks. It is seen that the effect of glare is enormous when the brightness-contrast of the object and its background is low. Also it is seen that by increasing the brightness-level the effects of glare diminish. At 100 footlamberts (100 footcandles on a perfectly white background) the effect of glare almost entirely disappears.

the brightness-level or illumination-level of the background was increased to 100 footlamberts (about 125 footcandles on the white background) the effect of this glare-source upon visibility almost disappeared. Ease of seeing also increased but was still reduced by the presence of the glare-source as is seen in the previous chapter by the blink-rate and other criteria. However, it is emphasized that high brightness-levels and footcandle-levels greatly reduce the undesirable effects of glare upon visibility and ease of seeing.

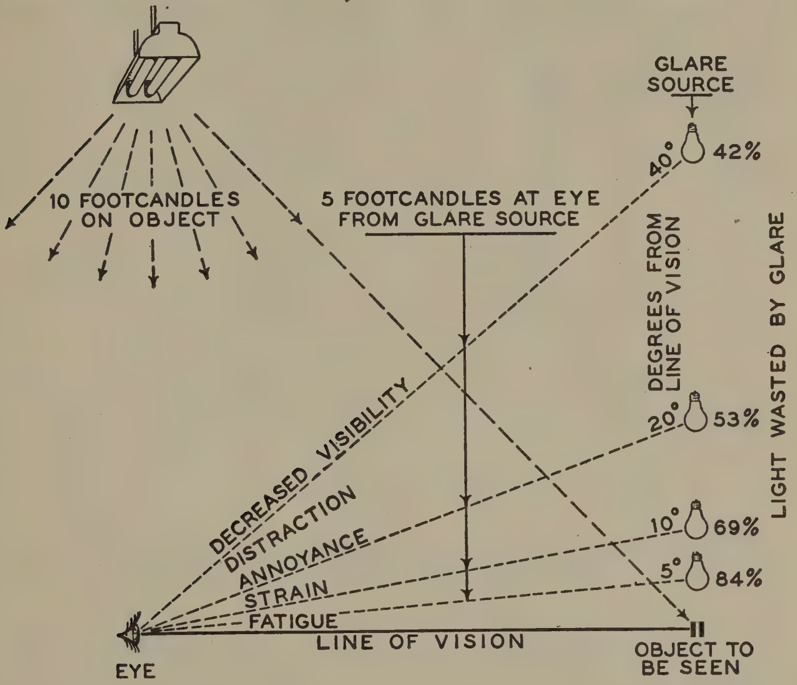


FIG. 73.—The reduction in visibility due to a moderately glaring light-source, at various degrees from the line of vision, is represented in terms of the waste of light which illuminates the object.

The effects of glare can be appraised from various viewpoints and they can be stated in percentage of wasted light. The results in the foregoing case are shown in Fig. 73 in terms of wasted light for one specific test-object and brightness-level. For example, when the glare-source was located 5 degrees above the line of vision, 84 percent of the light on the object was wasted. In other words, an object of the threshold size necessary to be barely visible when the glare was present, was visible under only

16 percent as much light when the glare-source was screened from the eyes. It is also seen that, from the viewpoint of visibility, when the glare-source was raised farther and farther above the line of vision, the waste of light became less and less. The waste was only half as much when the glare-source was 40 degrees above the line of vision as it was when the glare-source was only 5 degrees above the line of vision. The results differ considerably for objects of various brightness-contrasts with their background and for various glare-sources, brightness-ratios and brightness-levels.

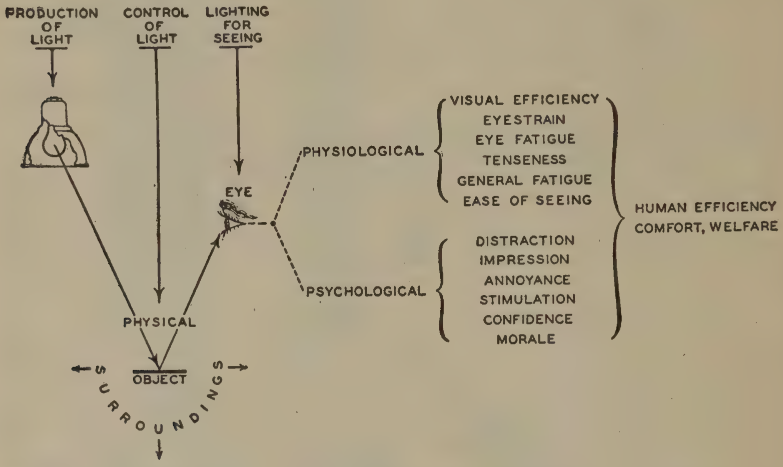


FIG. 74.—A diagrammatic view of light, lighting, object and surroundings and some of the physiological and psychological effects of seeing which result in human efficiency and welfare.

On the highways at night and throughout the indoor world of seeing by day and by night, preventable glare is taking an enormous toll in human efficiency, accuracy, safety and welfare. This represents not only economic waste in the narrow sense but also an unnecessary waste in human resources. Much of this glare can be reduced by proper lighting, by proper brightness of surroundings and particularly by providing levels of illumination for high visibility and easy seeing.

As a reminder that seeing is an activity of the entire human being, Fig. 74 suggests diagrammatically the three links—production, control and specification of light for seeing—and some of the physiological and psychological effects leading to human efficiency and welfare. Perhaps the reader should also turn back to Figs. 5 and 6. Brightness engineering is entirely a matter of controlling light after the reflection-factors of various surfaces are fixed. Adequate light is seldom available for most of our tasks of critical seeing. When it is available other factors, upon which visibility and ease of seeing depend, are too commonly neglected to make the most of the light available.

SPECULAR REFLECTION

Many surfaces reflect more or less imperfect images of light-sources, of bright portions of lighting equipment, and of large areas of bright sky or ceilings. Generally specularly reflected images are undesirable although in many specific cases they can be made to increase visibility. It is the problem of the seeing specialist to eliminate, or to reduce their effects when undesirable, and to utilize them as fully as possible when they can be used to advantage.

Place a sheet of glass over this page and note how the reflected images reduce visibility. They not only are glaring but they greatly reduce the brightness-contrast between the printed matter and the white background. This demonstrates how specular reflection operates unfavorably. On the other hand throw some pins on the floor and view them from various directions and even in deep shadows. Their highlights, which are specularly reflected images of bright sources or areas, render them highly visible even against a patterned floor covering. Also examine a steel scale as it is oriented in different directions. The specularly reflected image may be relatively bright and the dark rulings or divisions of the scale may become highly visible. In these cases we see additional examples of the great value of high brightness-contrasts.

The specular reflection-factors (SRF) of polished metal surfaces vary from low values to nearly 100 percent for highly polished silver. For a surface of glass or of water the SRF is about 4 percent, and for glossy papers and inks is of the order of 1 percent. Some of these values are small but they have an enormous effect upon visibility and ease of seeing if they reflect images of sources or areas of high brightness.

Unconsciously we take advantage of specular reflection many times daily in increasing visibility. We may orient a needle in order to thread it. We may walk around with the hope of seeing the glint of a small shiny object which has dropped to the floor. We may orient a metal or glass surface with respect to a large bright area in order to inspect it for scratches. When we wish to utilize specular reflection in any work-world task it is well to supply a localized source of the proper area and brightness and fixed in the proper position.

Very generally specularly reflected images are unfavorable because they reduce visibility and ease of seeing by being glaring and by reducing brightness-contrasts of critical details and their backgrounds. Their brightnesses can be reduced in proportion to the reduction of the brightness of the source or area whose image is being reflected. Wherever possible glossy or polished surfaces should be eliminated. For moderately specularly reflecting surfaces a sufficient increase in the level of illumination without increasing the brightness of the sources of light will completely submerge the reflected image. This can be achieved by properly directed localized light. However, curved glossy or polished surfaces are particularly annoying because too often some portion of them is properly oriented to reflect a bright image into the eyes.

It is interesting to study various specimens of glossy paper on which there is printed matter. If one orients these samples near a bright source of light, he may find a position at which the ink is brighter than the paper. This is due to the fact that the specular reflection-factor, SRF, of the ink is sufficiently greater than that of the paper to overcome the brightness of the paper due to diffuse and specular reflection. Such an ink is very undesirable even though it is generally somewhat "blacker" than non-glossy inks. Obviously such specular reflection can reduce the brightness-contrast between the printed matter and the background from the normally high values, of 95 percent or more, to very low values. This means that the visibility of the printed matter can be decreased by specular brightness to very low values and even to zero.

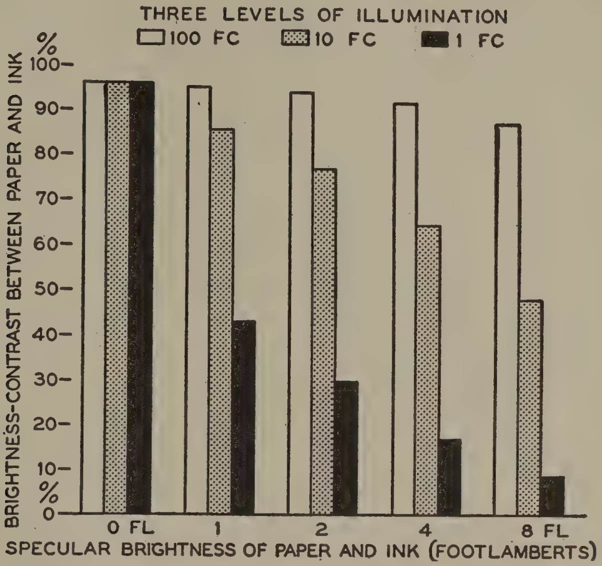


FIG. 75.—Reading matter was printed with glossy ink on glossy paper, both with a specular reflection-factor of one percent. The specular brightness due to the reflected images of bright lighting equipment varied from 0 to 8 footlamberts. The visibility of the printed matter depends upon its brightness-contrast with the white paper background. It is seen that a high level of illumination tends to overcome the effects of specular reflection. For example, at 100 footcandles the brightness-contrast of the printed matter is high. At one footcandle it diminishes rapidly as the specular brightness increases.

In Fig. 75 are shown how the brightness-contrast between the paper and printed matter is reduced by specular reflection and how effective higher levels of illumination are. We have had adequate evidence of the great importance of high brightness-contrast between the object and its background. Anything that reduces this also reduces visibility and ease of seeing. The SRF of paper and ink was one percent, which is a common value for glossy papers and inks. The DRF of the paper was 80 percent and of the ink was 3 percent.

The specular brightness of the paper and ink depends upon the brightness of the source of light whose image is specularly reflected. Obviously, the brightness of the source ranged from 100 to 800 footlamberts because the specular reflection-factor is determined by the brightness of the specularly reflected image in percent of the brightness of the source whose image is reflected. The former was one percent of the latter. It is seen that when the printed page is illuminated to a level of only one footcandle, the brightness-contrast decreases markedly as the specular brightness increases. The decrease is much less at the 10-footcandle level and is very little at the 100-footcandle level.

In this typical case of glossy paper and ink and in many other cases, the undesirable specular brightness and its very unfavorable effects upon visibility and ease of seeing can be reduced and practically eliminated by proper lighting. Often this is accomplished most easily by properly located and directed supplementary light, which provides a higher level of illumination. Besides reducing or even eliminating the unfavorable effects of specular reflection, the higher level of illumination, in itself, increases visibility and ease of seeing. Thus this dual contribution doubly justifies higher levels of illumination than are prevalent in our everyday world of prolonged critical seeing.

Perhaps the reader will find it of interest to turn back to Chapter VIII and note the relationships of brightness-contrast to the other fundamental factors such as size and brightness-level. In Chapter X its relationship to visual acuity is illustrated in Figs. 40, 42 and 43. In Chapter XI, Fig. 50 and the low-contrast test-charts are of interest. At the risk of too much repetition it is again emphasized that brightness-contrast is the most generally important factor in visibility and, therefore, in seeing. Every reasonable effort should be made to obtain or maintain high brightness-contrasts between the critical details of a visual task and their background.

PERMISSIBLE MAXIMUM BRIGHTNESSES

What is the maximum brightness that is permissible in the visual field? Owing to the variety of factors which determine permissible brightnesses, it is recommended that the brightnesses of light-sources and lighting equipment be reduced as much as is practicable by the use of shades and diffusing media. In this respect one is guided somewhat by the size of the interiors, the proximity of the occupants to the lighting equipment and the character of the seeing tasks. In all cases, localized light on the critical visual tasks can greatly reduce the undesirable effects of high brightnesses of light-sources and lighting equipment which provide general illumination. In the following discussion it is assumed that the surroundings are not too dark and that the background of potentially glaring sources is reasonably bright.

First let us examine the higher brightnesses outdoors. The brightness of the sun is about 1,000,000 candles per square inch when it is far above the horizon. Obviously it is so bright as to be actually harmful to the eyes if looked at for a sufficient period.

The next highest brightness that is common to all seasons of the year is a sunlit cloud with a maximum brightness of about 20 candles per square inch. Certainly this is not actually harmful to the eyes for they have been adapted to this brightness for eons. Sunlit snow can be equally bright, but it is obviously glaring owing to its great expanse which produces a very high illumination at the eyes. Snow-blindness is due to the ultraviolet energy which is not present in comparable quantities in *artificial* light of even very high intensities.

We can safely conclude that light-sources and lighting equipment having brightnesses of 20 candles per square inch are not actually directly harmful. However, such a brightness in the visual field reduces visibility depending upon its distance from the eye, which in turn determines the illumination at the eye due to this glare-source. Therefore, in large industrial interiors where these bright sources are quite distant from the eye, they are less glaring than in small interiors.

The brightness of the cloudless sky outdoors in the daytime commonly varies from one candle per square inch for a deep blue sky to about 4 candles per square inch for a hazy sky. These are safe brightnesses indoors, provided the seeing conditions are otherwise satisfactory and that these brightnesses are not directly in the visual field of persons who are performing tasks of critical seeing. However, a bright patch of sky seen through a window amid relatively dark surroundings is obviously annoying and glaring. In small interiors where light-sources of such brightnesses are in the visual field, they should be screened by means of shades or reduced in brightness by diffusing media.

It should be borne in mind that moderately bright sources or areas are glaring on account of the illumination which they produce at the eye. A glittering crystal of glass may have a brightness of several, or even many, candles per square inch but it may send so little light toward the eye as to be far less annoying or glaring than a much larger area of lighting equipment or ceiling of much lower brightness. It is ridiculous to insist upon a maximum brightness of a few candles per square inch for glittering elements of a decorative piece of lighting equipment, if these are responsible for only an insignificant amount of the illumination at the eye. Apparently a maximum of 20 candles per square inch is permissible for such insignificant "sources" of light. Many indirectly illuminated ceilings of relatively low brightness are really annoying and glaring owing to their large expanse and, therefore, to the large amount of light directed toward the eye.

One may also safely conclude that brightnesses as great as 20 candles per square inch are permissible for light-sources and lighting equipment for large interiors but they should be screened from the eyes in small interiors and wherever they must be hung relatively low. The brightest area of a frosted tungsten-filament lamp may have a brightness of 100 candles per square inch. If one or more of these are concealed behind a shade with a white inner surface, as in the case of properly designed portable lamps, the combination may be fairly satisfactory. If one is reading a magazine with glossy paper, he may be annoyed by specularly reflected images. However, if the total wattage of the lamps is sufficient to provide a fairly high level of illumination on the visual task, the undesirable effects of specular reflection may be greatly reduced and even eliminated.

Although reasonable efforts should be made to reduce the brightnesses of light-sources and lighting equipment, other factors should not be lost sight of. For example, the diffusing bowl which is concealed within the outer shade of modern socalled "sight-saving" portable lamps need not be limited in brightness to 3 candles per square inch. It need not be visible at all. Obviously the amount of light emitted directly to the visual task is limited by the brightness of this diffusing bowl. For example, with a 300-watt tungsten-filament lamp inside this concealed diffusing bowl, having a brightness of 3 candles per square inch, about 25 footcandles are obtained on a book one might be reading. If the brightness of the bowl were increased to 6 candles per square inch, the effective direct light would be about doubled. Enough light would still be emitted upward toward the ceiling to contribute desirable illumination to the general surroundings. The specification of a limiting brightness of 3 candles per square inch for this concealed inner bowl is not justifiable when it results in a great sacrifice of desirable footcandles on the visual tasks, such as reading and particularly sewing. Even the full moon has a brightness of 3 candles per square inch.

Modern fluorescent lamps have brightnesses within the range of about 3 to 6 candles per square inch. These are permissible brightnesses if they are not ordinarily in the visual field of the occupants of small interiors. If they are concealed within the shades of portable lamps, their brightnesses are reasonably satisfactory. In small interiors such as kitchens and bathrooms, where they are not in the visual field for long periods, they need not be equipped with shades or diffusing media. In living rooms, dining rooms, offices and many other relatively small interiors, they should be screened from the eyes.

Good seeing conditions are necessarily a compromise of various factors. Compromise requires the exercise of judgment but it should involve adequate consideration of the factors which result in glare and also in high visibility and good seeing conditions. Generally in interiors glare and its effects are due chiefly to the light—footcandles—reaching the eyes directly from the glare-sources. Therefore, other factors remaining constant, the permissible brightness of a visible light-source or portion of lighting equipment increases directly with the square of its distance from the eye.

A great expanse of relatively bright ceiling, as in the case of socalled indirect lighting in large interiors, can be quite glaring even if its brightness is only a small fraction of one candle per square inch. In this case the ceiling is several times brighter than this printed page would be, and would be 10 or 100 times brighter than visual tasks of lower reflection-factors than the white paper of this page. This has been shown to be a poor condition for seeing. Additional footcandles on the critical visual tasks by means of direct components of light from ceiling fixtures or by means of supplementary localized lighting greatly improve the lighting and seeing conditions. They increase ease of seeing by increasing the visibility of the task and by decreasing the glare from the large expanse of bright ceiling. Furthermore, if the visual task and its immediate surroundings are brighter than the ceiling, the psychological effects of better concentration and of better seeing are generally favorable results that are well worth while.

In ordinary interiors such as homes, schools and offices, most light-sources should be screened from view or their brightnesses should be reduced by diffusing media. This is obvious from their brightnesses which in candles per square inch are approximately as follows: candleflame, 9; brightest spot of inside frosted lamps, 30 to 200; bare tungsten filaments, 1000 to 10,000; fluorescent lamps, 3 to 6. Some light-sources at the present time which are suitable for lighting large industrial interiors and large areas outdoors at night have brightnesses from 500 to 30,000 candles per square inch. Common observation reveals no great amount of glare from these if they are sufficiently distant. A lighthouse of a billion candlepower is a benign light-source when seen on the distant horizon.

CHAPTER XV

Light and Color

Color is generally a secondary aspect of visibility and seeing which is superposed upon the more basic world of brightness. It is very generally of far less importance in critical seeing than brightness which in its various aspects is the backbone of visibility. Of course, there are special cases where color-discrimination is important and where color and color-contrast have been used for distinction, realism, attention, attractiveness and other purposes. Whereas low visibility and poor seeing conditions are generally due to indifference to or ignorance of brightness-factors, color and spectral quality of light seem to be open doors for over-emphasis of their importance even to and beyond the borderline of quackery. Color and colors are particularly important in supplying a magical drapery which makes our environment more pleasant and interesting. In many cases they add good measure to the refinement of seeing conditions.[47] However, many unsupported claims are made for tinted papers, colored glasses, colored lights and certain special illuminants. It is the responsibility of the seeing specialist to separate the good from a maze of confusion.

VARIOUS COMMON ILLUMINANTS

It may be stated categorically that no illuminant which is suitable in spectral character for general use in lighting has any advantage over other suitable illuminants in the basic matter of critical seeing. This statement is based upon many researches involving thousands of measurements of visibility, of visual acuity, of speed of seeing and of minimum perceptible brightness-difference. Many of these data have been published elsewhere and need not be included here.[6] In other words, at brightness-levels above 0.1 footlambert no basic difference in the visibility or read-

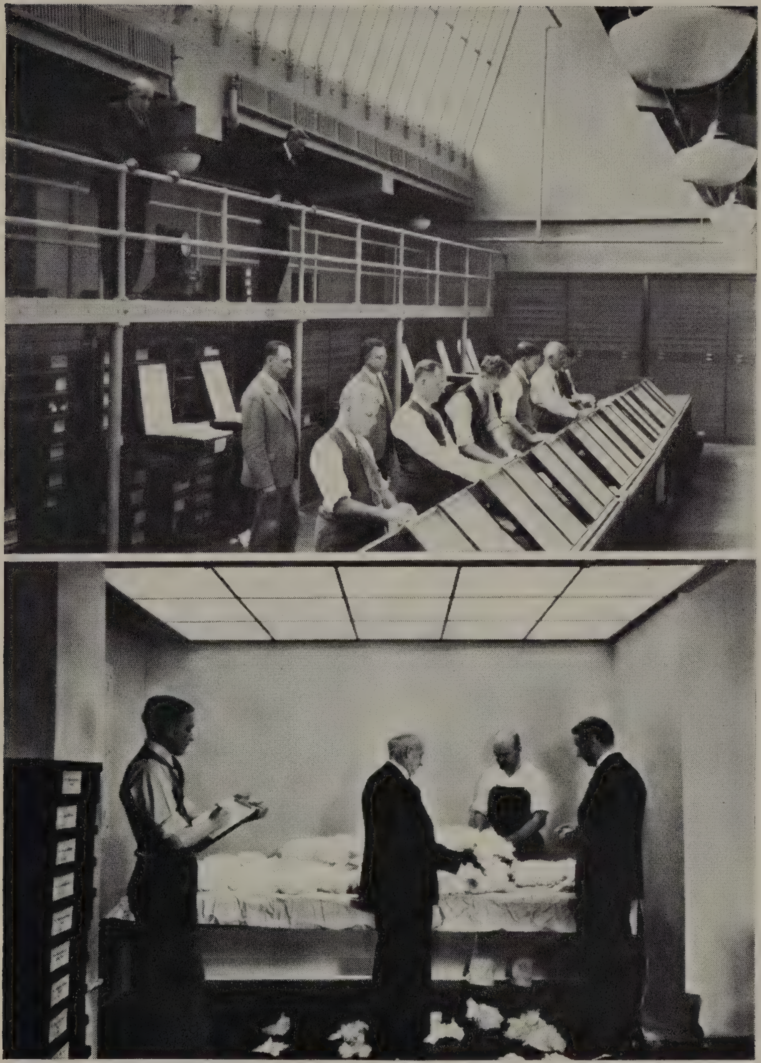


PLATE XV.—In discriminating and matching colors, natural daylight is gradually yielding to artificial daylight obtained with filters and phosphors. For classifying cotton, the U. S. Department of Agriculture tests an experimental installation of artificial daylight in terms of experience with the natural daylighting in the upper illustration.

ability of this printed matter, for example, is found for light from the sun or sky, from tungsten filaments, from mercury arcs, from fluorescent lamps or from any other source which radiates energy throughout the spectrum or in a sufficient number of spectral regions throughout the spectral range to which our visual sense responds.

This statement applies to all illuminants of extended spectral range where colorless objects and backgrounds comprise the task. It also applies to present-day colored fluorescent lamps and those illuminants that are occasionally exploited as having peculiar spectral characteristics which make things more visible and make seeing easier. No illuminant, among those having a sufficient spectral range so that they do not distort colors too much to be used for general lighting and seeing purposes, has any known basic advantage over another illuminant from the viewpoint of seeing.

If among such illuminants there is no advantage from the viewpoints of visibility, visual acuity, brightness, brightness-contrast and speed in the case of colorless or nearly colorless objects and backgrounds, one may scarcely expect any difference in ease of seeing. However, we have applied the blink-rate criterion to subjects who read material printed with black ink on tinted papers and also to subjects who read ordinary printed matter under various common illuminants. The results invariably have shown no measurable advantage for tinted paper but a marked disadvantage in all cases when the color or tint resulted in an appreciable decrease in reflection-factor below 80 percent, which is a common value for white paper.[48] Inasmuch as these tests involved the blink-rate while reading black print on various backgrounds, any decrease in reflection-factor of the background decreased the brightness-contrast. This in turn decreased the visibility and readability or ease of seeing.[1]

In Fig. 76 are shown some typical average rates of blinking for four tinted or colored papers. No significance is attached to the slightly lower rate for the cream-tinted paper. The same results were obtained for papers of very light tints of green. No significant difference in the rate of blinking was obtained unless the reflection-factor was appreciably less than that of white paper. Then the result was unfavorable; that is, the blink-rate increased. Therefore, for various reasons there appears to be no measurable virtue in tinted papers from the viewpoints of visibility and ease of seeing. Very light tints can be used as suit the taste without decreasing visibility appreciably but from the knowledge available one must conclude that no tint is "easier on the eyes" than white paper. Perhaps some tints may be "easier on the esthetic sense" but this is beyond the scope of the present discussion.

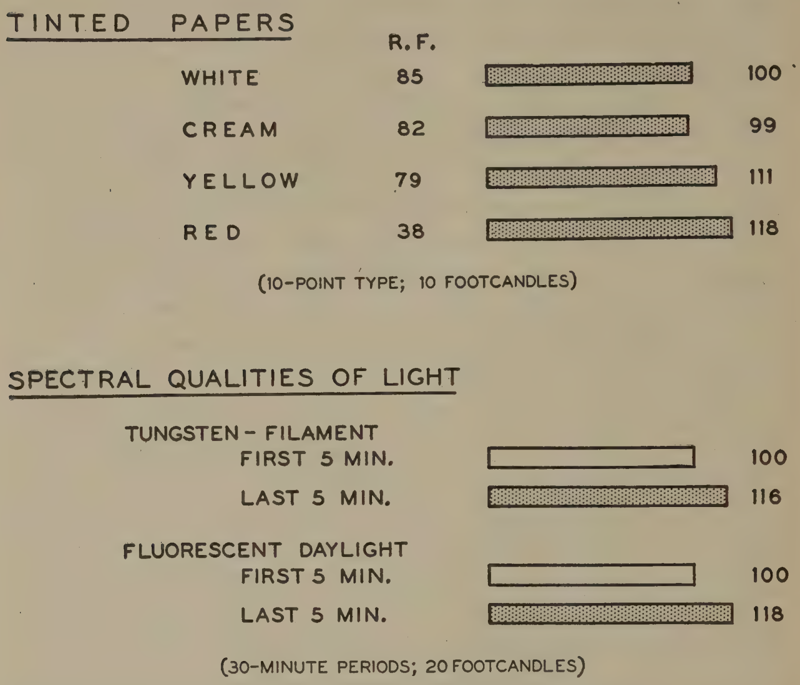


FIG. 76.—The rate of involuntary blinking reveals no advantage in the use of tinted paper. Actually if the tint appreciably decreases the reflection-factor of the paper, it also decreases the brightness-contrast between the printed matter and its background. The result is that readability or ease of seeing, as indicated by the rate of blinking, decreases. In the lower diagram it is seen that the rate of blinking does not indicate any difference in ease of reading for light from tungsten filaments or from modern fluorescent lamps. This sensitive criterion has revealed no differences in ease of seeing among all the illuminants satisfactory for general lighting purposes.

In every case in which we applied the blink-rate criterion while reading black print on white paper under a given level of illumination provided by common illuminants, no material difference was found in the ease of reading. Typical results are shown in Fig. 76 for two illuminants differing considerably in integral color from the yellowish white of tungsten-filament light to the white or bluish white light from the fluorescent daylight lamp. Obviously this range in integral color includes all common illuminants that are satisfactory for fairly general use.

SODIUM LIGHT

Various claims have been made for markedly yellow light which have been proved erroneous. Yellow light does not appreciably penetrate fog better than white light. Yellow glasses and papers are not generally "easier on the eyes" as claimed. If we are outdoors and wish to reduce the glare of the sky, yellow-green or yellow glasses do absorb blue light more than light in other parts of the spectrum. Also outdoors when there is an abundance of light, certain colored glasses do reduce the bluish haze somewhat. This slight advantage added to the decrease in the brightness of the sky recommends yellow-green and yellow glasses for comfort and for some tasks of critical seeing. There are always special uses for distinctive or pronounced colors in paints, papers, eyeglasses and illuminants but it is a common mistake to argue from the specific to the general case.

As shown in Fig. 8, one defect of the eye, known as chromatic aberration, indicates that monochromatic light—light confined to a very narrow portion of the spectrum—has advantages in seeing very small objects near the threshold in size. For normal vision monochromatic green, yellow, orange and red lights are best. Actually, this was proved to be true many years ago but until the sodium lamp was developed there was no suitable and efficient monochromatic illuminant. Practically all the visible energy in sodium light is radiated in the yellow region of the spectrum. The color of sodium light is the deep yellow noticeable when common salt is spilled in the Bunsen flame of a gas range.

A spectroscope will reveal the characteristic twin "lines" of sodium. We have investigated this interesting illuminant in many ways to ascertain its advantages, if any, in special problems of seeing.

Sodium light is undesirable for general use because all color disappears excepting yellow, and a world of shades of yellow remains. Careful measurements reveal no appreciable advantage in penetrating fog [49] and no advantage in enhancing contrasts in general. However, its distinctive color may be used to advantage as a caution light and it has other advantages in special cases.

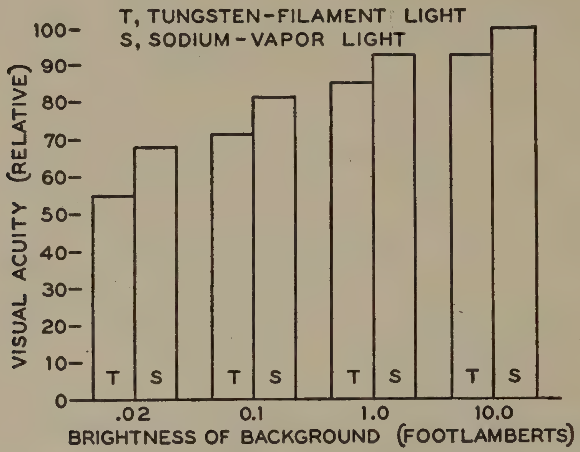


FIG. 77.—Visual acuity is greater for a given footcandle-level of sodium light than of tungsten-filament light. This advantage holds only for objects at or near the threshold in size. For relatively large type or other objects this advantage disappears.

In Fig. 77 are shown the results obtained with very small black test-objects on a white background. It is seen that, for this special case, visual acuity is measurably greater for sodium light than for tungsten-filament light or any other illuminant of extended spectral character. However, for objects well above the threshold in size, this advantage of sodium light or of any monochromatic light disappears.[50] For example, the visibility of the printed matter on this page is not measurably greater under sodium light than it is under various common illuminants because the sizes of critical details are well above threshold. Furthermore, when threshold sizes are relatively large as they are when their brightness-contrasts with their background are small, the advantage of sodium light or of any other monochromatic illuminant disappears. The effect of chromatic aberration upon the "definition" or "sharpness" of the retinal image of an object is confined entirely to the edges of the object. Obviously, when the object is large a slight fuzziness of the edges plays no appreciable part in the visibility of an object.

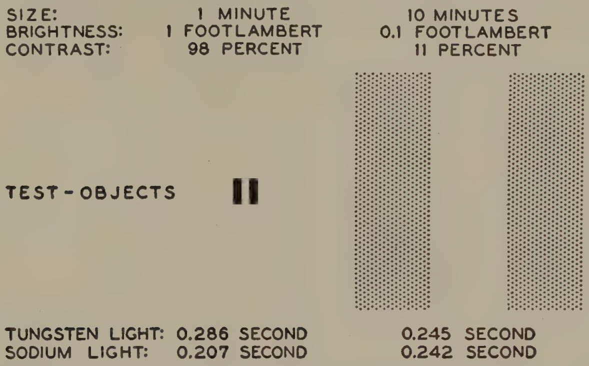


FIG. 78.—The time required to see appears to be related to the same factors as visual acuity is. Very small objects are recognized more quickly under sodium light than under tungsten-filament light. This difference entirely disappears for relatively large objects.

This is involved in the results shown in Fig. 78 on speed of seeing. The critical detail of the black test-object is one minute in visual size and is barely visible to subjects possessing excellent vision when the brightness of the background is one footlambert. The least time necessary to recognize it was 38 percent greater under tungsten light than under sodium light. However, for a light gray object, 10 times larger and having a brightness-contrast of only 11 percent with its background, the minimum time necessary to recognize it was about equal for the two illuminants. Thus it is seen that only for very small objects close to the threshold in size—and these must be of high contrast—is monochromatic sodium light advantageous. There are many applications for such an illuminant. However, one should not make the error of arguing from the specific case to the general case.

Extensive tests with sight-saving pupils revealed no advantage of sodium light over tungsten-filament light. Doubtless the reason is that the objects must be quite large for these partial-sighted pupils to see them at all. The result is that any greater sharpness of the edges of the objects plays a negligible part in the visibility of the objects.

ENHANCING CONTRAST

It should be obvious that a judicious use of color can superimpose color-contrast upon brightness-contrast. In many cases color can be used to delineate details or surfaces. However, when both color and brightness are fixed something can still be done with light of the proper color or spectral quality.

In special cases of seeing involving colored details and backgrounds or both, a properly chosen colored illuminant can be used to enhance brightness-contrast. Suppose white or light gray details are to be seen on a red background. Under mercury light containing little or no energy in the red portion of the spectrum, the red background will appear almost black with probably a residual brownish color. Obviously the brightness-contrast of the details and their background is enhanced. Suppose black or dark gray details are to be seen on a yellow background. Under sodium light the yellow background will appear relatively brighter with the result that the brightness-contrast is increased. In many cases of seeing where the "natural" appearance of color is not important, contrast and, therefore, visibility can be enhanced by selecting the proper colored or tinted illuminant from the variety now available.

COLOR-DISCRIMINATION

There are many cases where color-discrimination and color-matching are of great importance.[51] For many years various types of artificial daylight have been developed for the purpose. An almost universal fault of such illuminants has been the difficulty or impracticability of obtaining high levels of illumination. In addition, there has not been a proper appreciation of the need for relatively high levels of illumination for discriminating small differences in color. Even in such a case as grading cotton, the very small differences in tint require a fairly high level of illumination in order to make them reasonably visible. Besides this, the distribution of light and brightness is important. Most things are at least slightly glossy. Therefore, the specularly reflected images of bright sources and areas can do much to obliterate, or at least to partially submerge, the slight differences in tint.

When the colored materials possess low reflection-factors it has been too generally lost sight of that brightness is a powerful factor in seeing colors as well as in seeing objects and critical details. Suppose various "black" fabrics are to be compared or matched. Some blacks are bluish, others are neutral and some are brownish. These black fabrics may reflect only two percent of the incident light. To make them as bright as this page is under 10 footcandles, these fabrics must be illuminated to a level of about 400 footcandles. This is one of the reasons why we go to a window or outdoors to see the color of dark goods. At least 100 footcandles are necessary for easily discriminating colors of a wide range of reflection-factors. For colors of low reflection-factor 500 or 1000 footcandles are desirable.

Combinations of various fluorescent lamps and also combinations of tungsten-filament and fluorescent lamps have been successfully used for color-grading. With these, relatively high levels of illumination are practicable and there remains no excuse for trying to appraise colors under the prevalent low footcandle-levels.

The appearance of a color depends upon the illuminant. Therefore, color-discrimination and even color-matching should be done under the illuminant under which the color or colors are to be seen. Evening gowns are generally seen under night illuminants in home, theater or ballroom. Suits, on the other hand, are seen in the daytime, at least some of the time. To most of us the "actual" or "natural" color of an object is its color in daylight. Many mistakes are made in selecting colors under the wrong light in stores and elsewhere which results in some great disappointments later. Even facial make-up should be applied under an illuminant simulating daylight or night light as the case may be. Certainly much remains to be done in the realms of seeing which involves the appearance, matching and discrimination of color. The decorators, the shop, the furniture store and other places are generally remiss in providing adequate light of the proper spectral characters to aid the customer. Some progress has been made, but only a beginning. For example, in the selection of furniture and floor coverings only meager light of accidental quality is generally available. Even high levels of illumination from any common illuminant are great aids in seeing color.

Certain precautions should be exercised. Materials such as paints and wall papers should be judged finally under levels of illumination that they are likely to receive in actual use. For example, it is unwise to choose them under excessively high levels of illumination which sometimes result from a special lighting unit used in showing them to the prospective customer. They may appear to be much "lighter" in shade or color than they actually are under the level of illumination they will receive in actual use.

In other words, when eventually applied to an interior they may be too "dark" to be entirely satisfactory. A given color will appear of different "shades" under different levels of illumination just as definitely as if various percentages of black had been mixed with the original color. Furthermore, extremely high levels of illumination tend to "desaturate" colors. For example, note how the artist paints a red fabric a lighter, less saturated orange-red in the highlights and a deeper red in the shadows. Light and color are so intricately interwoven that many surprises and mistakes await those who consider color apart from light and lighting.

SOME PSYCHOLOGICAL ASPECTS OF LIGHT

Color and colors make their appeal largely through the esthetic sense or, more broadly, through psychological avenues.[47] The eyes are doorways for impressions as well as tools for seeing, but esthetic aspects are outside the scope of our present objective. It is sufficient to emphasize that color and colors can be used sometimes to make seeing easier and always to make seeing conditions more pleasing and interesting. However, inasmuch as light and lighting are the universal controllable aids to seeing, some comments on color or spectral quality of light are in order.

We have found it helpful to think of human beings as day-beings and night-beings. These also generally correspond to work and to leisure. An illuminant eminently satisfactory for work and for work-places is not necessarily acceptable in the home and other places where we relax.

For many years it has been a dream of laboratories engaged in developing light-sources to produce illuminants which blended well with daylight and even closely simulated the spectrum of average daylight. Some daylight, meager though it may be, finds its way into interiors of the work-world. When artificial illuminants were decidedly yellowish they did not blend with daylight and they were not entirely suitable to day-beings or work-beings. Now certain high-pressure mercury arcs and particularly certain fluorescent lamps meet this need very well. They are satisfactory for work-places in the home such as the kitchen, laundry, workshop and bathroom. With continued improvement they should eventually very closely simulate the spectral character of any desirable daylight for the discrimination and matching of colors.

In the home and in other places where human beings relax they are essentially night-beings. In the home, for example, a "warm-tinted" illuminant, such as the flame sources, is just as "natural" as daylight is for work-beings. The crude homes of the first primitive families were illuminated by flames and homes have been so illuminated until very recently. During the past decade or two there is evidence of a tendency to accept less yellowish light and "whiter" shades in the home. However, this is still representative of the fields in which white light is still far from acceptable. Even the yellowish white light from ordinary tungsten-filament lamps is commonly tempered by warm-tinted shades. Therefore, it appears likely for some time to come that illuminants, to be acceptable in the home, aside from the work-places, and in other places of similar atmosphere, must be yellowish white. Besides, the harshness of bare and bright sources must be reduced by shades and diffusing media. Recognition of these fundamental psychological factors is necessary to make the most out of lighting for satisfactory seeing.

GLARE FROM VARIOUS ILLUMINANTS

Various unwarranted claims are sometimes made in regard to the absence of glare for certain illuminants. Various researches have established no advantages of one illuminant over any other for the same brightness conditions. Often these claims arise innocently by not taking into account other differences besides color. Extensive researches with common illuminants and also sodium light have revealed no particular virtue of color or spectral quality from the viewpoint of glare. Even researches with moderately colored illuminants—canary, amber, light blue and ordinary tungsten-filament lights—revealed no measurable differences in glare from sources identical in position, size, brightness and candlepower.[52] It is possible that eventually some advantage of a certain color or spectral quality of light may be discovered. However, from the considerable research already prosecuted it is unlikely that any appreciable advantage of color of much practical importance will be proved.

COLOR-TEMPERATURE OF ILLUMINANTS

In the laboratory we have various ways of designating color and the spectral character of illuminants. Most of these are of little interest excepting to specialists. However, during recent years a laboratory designation in terms of color-temperature has come into extended outside use. In physical science a socalled black-body is a theoretical radiator of energy which is essential to the development of certain fundamental laws of radiant energy. For our purpose we may assume that a carbon filament has the characteristics of this black-body. If we increase the temperature of this filament sufficiently by passing enough electric current through it, it will glow a deep yellow color. As we increase the current the light becomes less yellowish. If the carbon filament could withstand any temperature the integral light would be white or colorless when the temperature reached the neighborhood of 6000 degrees Kelvin.

Actually no filament has exactly the characteristics of the theoretical black-body so the integral color of the light is expressed in color-temperature which would be the integral color of the light from the black-body at that actual temperature. If the temperature of the filament were increased beyond 6000 or 6500 degrees Kelvin, the light would become bluish white. With further increases in temperature it would become bluer and bluer.

The color-temperatures of common illuminants are approximately as follows in degrees Kelvin:

Noon sunlight on a clear day, 5400 to 5800.

Noon sunlight plus light from a clear blue sky, 6100 to 6500.

Light from an overcast sky at midday, 6700 to 7000.

Light from an average clear blue sky during midday 12,000 to 26,000. On a very exceptional day, it may be nearly 40,000.

Tungsten-filament lamps used for general lighting purposes, 2500 to 3100 for the range from 15-watt to 1000-watt lamps. The 100-watt lamp has a color-temperature of about 2800. Tungsten-filament "daylight" lamps from 3500 to 4000.

Fluorescent lamps can readily be made to provide light of a wide range of color-temperature. At present that of the fluorescent daylight lamp is about 6500. Lamps of lower color-temperatures are available.

ULTRAVIOLET ENERGY ACCOMPANYING LIGHT

The light or visible energy emitted by light-sources is generally accompanied by invisible ultraviolet energy of shorter wavelengths than the visible energy and by invisible infrared energy of longer wavelengths.

The visible spectrum extends over a range from $\lambda 4000$ (a wavelength of 4000 Angstrom units) to about $\lambda 7000$. Actually the range varies somewhat for different eyes and different brightness-levels.

The solar spectrum extends into the ultraviolet region nearly to $\lambda 2900$. Human eyes and human beings are adapted to reasonable exposures of this ultraviolet energy outdoors. However, the ultraviolet energy near the end of the spectrum of outdoor sunlight and skylight causes sunburn and kills germs.

The ultraviolet spectrum of light-sources can be restricted so as to be safe for human eyes and skin. Nevertheless, a light-source that is safe when used properly by screening it from the eyes or by means of diffusing media might cause inflammation of the outer membrane of the eyes if it is close to them and unshaded. Good lighting with a minimum of glare results from such precautions. Responsible manufacturers provide safe light-sources if properly used. This is true of many other products.

Certain illuminants efficiently produce the "beneficial" ultraviolet energy which we recognize as a desirable characteristic of sunlight. Therefore, it is possible to supply this component of ultraviolet energy along with light for seeing. This has not been done as yet on a large scale but there is no reason to doubt that it will be done eventually. Certainly it is within the province of the lighting industry "to bring the outdoors indoors." This means not only producing the proper brightness-levels indoors but also providing certain components of ultraviolet energy which are safe and beneficial when properly used.

INFRARED ENERGY ACCOMPANYING LIGHT

The infrared energy beyond the red or long-wave end of the visible spectrum has no known harmful effects excepting those due to excessive heating. The infrared energy[53] accompanying light is, at its worst, annoying due to its heating effects. From this viewpoint the characteristics of a light-source, and particularly its luminous efficiency (lumens emitted per watt), are of considerable interest. Incidentally we have found that, for blindfolded subjects, the level of illumination on the forehead for a barely noticeable heating effect is about 125 footcandles for tungsten-filament lamps. For fluorescent lamps (white and daylight) the illumination was about 600 footcandles for a barely noticeable heating effect.

We have conducted several researches for the purpose of ascertaining whether the infrared energy accompanying light causes eye-fatigue or any other undesirable effects. Most of the infrared energy can be absorbed by a glass cell containing water of a depth of one inch or more. With and without this filter, which absorbed about three-fourths of the total radiant energy, we found no significant effects while reading for one-hour periods under 100 footcandles of tungsten-filament light. The criteria used were the blink-rate, the decrease in the convergence reserve of certain eye-muscles, the increase in the diameter of the pupil, the rate of reading and the time required to perform a special visual test.

It is interesting to compare various illuminants from the viewpoint of total radiant energy which accompanies a footcandle of illumination. Actually this energy is measured in terms of microwatts per square centimeter but the reader need not bother about the unit. The comparative values are of chief interest. The approximate values for common illuminants are as follows:

Clear skylight through window glass	5
Noon sunlight outdoors	9
Noon sunlight through window glass	7.5
White fluorescent lamp, 40-watt	8

Fluorescent daylight lamp, 40-watt	10
White fluorescent lamp through window glass	3.5
Fluorescent daylight lamp through window glass	4.5
Tungsten-filament lamp, 200-watt	40

From the foregoing it is seen that relatively "cool" artificial light is available from fluorescent lamps. In this respect these illuminants are comparable to sunlight and skylight outdoors. The foregoing values apply only to the radiant energy which accompanies the light. It does not include any energy re-radiated by the lighting equipment and accessories.

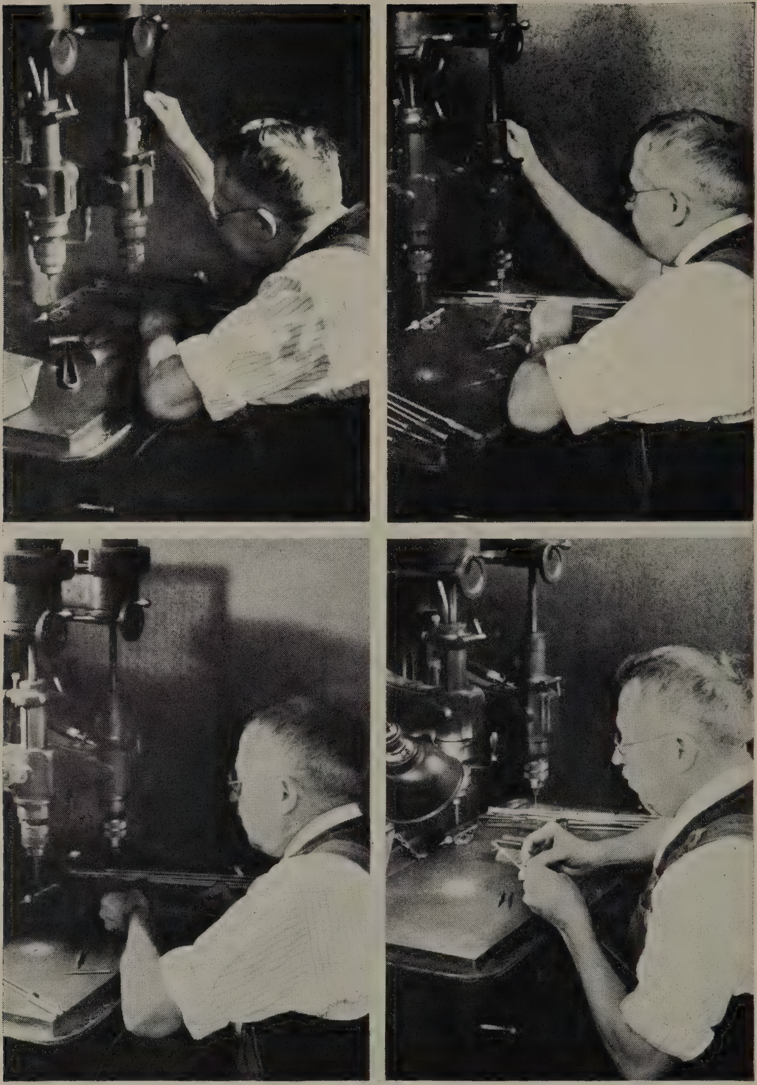


Plate XVI.—Light as a partner of eyesight may be a help or a hindrance just as correct or incorrect eyeglasses are. Adequate light and proper lighting are intricately interwoven with human efficiency and welfare.

CHAPTER XVI

Efficiency, Safety and Easy Seeing

It is axiomatic that if very poor seeing conditions are improved, by any means, the quality and quantity of useful work done should increase. This should be equally true of the reduction of accidents. Considerable attention has been given to the effect of see-levels and seeing conditions upon the production of useful work. One good reason is that much of the fundamental research can be performed in laboratories under properly controlled conditions. However, the effect of seeing and of seeing conditions upon safety or accidents does not lend itself to laboratory investigation. The relationship of seeing and safety must be studied by analyzing statistics. Naturally, the science of seeing supplies much knowledge of light, vision and seeing which is just as pertinent to safety as it is to any other objectives of high visibility and easy seeing.

If the seeing specialist is armed with adequate knowledge of the facts and principles upon which quick, accurate and easy seeing depend, he can diagnose and revise seeing conditions so that satisfactory performance, production and safety result. It is not necessary to go into detail, or to prove in every case that conditions which result in high visibility and easy seeing also increase production, decrease spoilage of materials, and reduce the number of accidents. Besides, there are many other benefits of better seeing to workers as well as to employers, all of which add up to more and better work done and to the conservation of human resources. Some of these benefits are axiomatic, others can be proved and some have not been measured quantitatively. A number of them are extensively recognized but important ones are not.

Among the tangible and intangible benefits arising from high see-levels and good seeing conditions in general are

1. Increased rate of performance of useful work done which results in decreased costs.
2. Increased accuracy which results in better work and less waste of materials, thereby decreasing costs.
3. Increased ease of seeing which results in the conservation of human resources, such as eyesight, energy and time, through the reduction in eyestrain, nervous tension, eye-fatigue, general fatigue, annoyance and mental fatigue.
4. Increased safety through quick, certain and easy seeing which reduces the enormous material and human losses due to preventable accidents.
5. Increased morale resulting directly or indirectly from the foregoing and from other psychological factors such as cheerful surroundings which are an inevitable result of good seeing conditions.

It has been adequately proved that high see-levels and good seeing conditions on the payroll are profitable. In fact there is much evidence that these aids to performance, production and safety would actually cost less than nothing if applied everywhere indoors and on streets and highways at night.

AN EXTENDED VIEW

The efficiency of a worker performing critical tasks of seeing is not measured by the amount of work he does per hour or per dollar. This may be his efficiency from a very narrow viewpoint of an employer. However, the proper concept of the efficiency of a worker is that which we use in considering a motor or any other machine that performs useful work. The efficiency of a human seeing-machine, as is true of any other machine, is the ratio of the useful work done to the total of useful and useless work done. It might also be stated as the ratio of the price he is paid to the price he pays in human resources.

At the end of a day's work it is not merely a matter of the useful work done—the number of pages read, the number of pages typed or the number of things done, made or inspected. This is useful work but how about the human seeing-machine or, more broadly, the human working-machine? How much useless work has he done? How about the wear and tear on eyes, nerves, muscles and mind? How about the waste of his resources? How about the expense to the worker as well as to the employer? In connection with such questions it is well to remember that more than a day's work is involved. Efficiency and progress involve the lifetime of workers, most of whom carry unnecessary burdens and pay unnecessary penalties of low see-levels and poor seeing conditions.

All these questions can be asked not only in the interest of those who work for direct pay, but also in the interest of school-children, of housewives, and of others engaged in prolonged tasks of critical seeing. For all these, the ease of performance of a visual task and the conservation of eyesight and other human resources greatly outweigh any considerations of rate of performance of a visual task or of useful work.

Many years ago we developed this broader concept of seeing as an activity of the entire human being. Fig. 79 is a simplified diagram which we have found to be helpful. Admittedly, we cannot evaluate useless work, wear and tear on the human being or waste of human resources. However, we know that, if type is very small, or the light is meager, or the seeing conditions are obviously poor, we read more slowly than if the reading task is made easier. The same is true of any other prolonged task of critical seeing. As visibility increases, seeing becomes easier and the rate of performance of useful work increases. Eventually it reaches an optimum as illustrated by the series of deeply shaded blocks in Fig. 79.

For many ordinary tasks involving details considerably above threshold in size, such as the printed matter on this page, the rate of performance of useful work reaches an optimum at levels of illumination of 10, 20, or 30 footcandles. It may continue to increase slightly for higher levels of illumination but this increase is relatively small. Therefore, we are generally more concerned with the practical optimum than by the absolute maximum. From the narrow viewpoint of efficiency, the optimum level of illumination for such tasks would be 10, 20 or 30 footcandles as the case might be. For others, inherently more difficult, the optimum level of illumination is higher. But how about the real efficiency of the human seeing-machine?

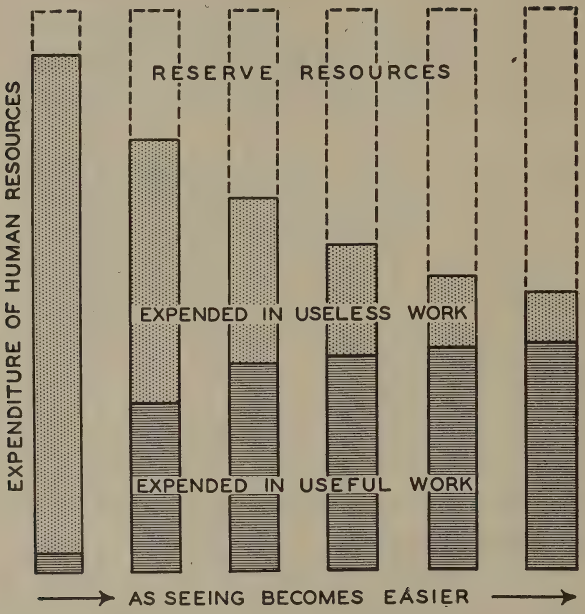


FIG. 79.—As seeing becomes easier, the production of useful work increases and the expenditure of human resources in useless work decreases. The overall efficiency of a human seeing-machine or a human working-machine continues to increase even after the production of useful work ceases to increase appreciably. Furthermore, the reserve resources also increase. The real efficiency of a worker is the ratio of expenditure of human resources expended in useful work to the total expenditure in useful and useless work. The efficiency of a worker is not measured merely by the useful work he performs per dollar or per hour.

In Fig. 79 we have tried to illustrate the expenditure of human resources in useful work and useless work. After the useful work ceases to increase materially, the expenditure in useless work by the human seeing-machine continues to decrease as the critical task of seeing is made easier and easier. Any aid to seeing is analogous to oil for other machines. In the expenditure of human resources we may group all unfavorable effects of seeing which have been discussed in Chapter XIII and other chapters. And in this connection we should practice thinking in terms of months, years and even lifetimes of performing the critical tasks of near-vision.

The results of many researches support such a diagram as Fig. 79. In the upper portion are unused or reserve resources. Obviously when seeing is extremely difficult we have to call upon all or a large portion of our resources which are involved in seeing. As seeing becomes easier the reserve of unused resources increases. In other words, we might consider that a larger part of the human seeing-machine is freed of unnecessary burdens just as electric motors and other machines have lifted much of the burden from human backs and muscles. There is no doubt that some such diagram as Fig. 79 represents the same proper concept of easing the burdens of seeing as is commonly applied to easing other burdens of human beings.

PRODUCTION OF USEFUL WORK

With the foregoing extended view let us discuss briefly productive or useful work.[7] Decades of research have yielded results and by-products revealing the effects of seeing upon production. Within certain limits there are always increases in the quality and quantity of performance of useful work when seeing is made easier. However, as a criterion of optimum levels of illumination, optimum type-size or optimum use of any controllable factor in seeing, productive work or the rate of performance of a visual task is inadequate. However, it is of practical interest.

It has adequately been proved by research and in practice that accuracy increases as visibility increases and as seeing conditions are improved. In addition to these direct proofs, many of the fundamental data on threshold size and visual acuity provide direct testimony. It has been shown that accuracy increases with the brightness-level. In a typical case it improved 14 percent when the level of illumination was increased from 1 to 10 footcandles. It increased another 8 percent when the illumination was increased from 10 to 100 footcandles. Accuracy is also influenced by lighting conditions, brightness of surroundings, glare and any other factor which affects visibility and ease of seeing.

In Fig. 80 are shown the results of a well-controlled investigation involving expert operators of key-punching machines in a statistical department. They have to read certain copy and punch the machines accurately. The initial general illumination was about 8 footcandles. To this was added excellent localized lighting which increased the level of illumination on the critical tasks to 60 footcandles. The investigation covered a range of nearly three years. The average effect upon production and errors is shown for each of two full years after the localized light was added. At the end of the first year, production (P) had increased an average of 23 percent and errors (E) had decreased to 53 percent. Compared with the average performance of the operators before the improvements in lighting and seeing were made, the average increase in production the second year was 46 percent and errors decreased to 31 percent. The operators were skilled by years of experience when the investigation was begun and the same operators continued throughout.

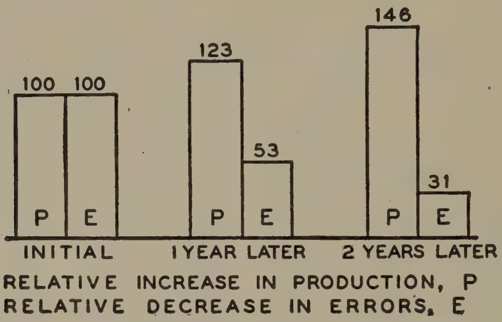


FIG. 80.—Showing the increase in production *P* and decrease in errors *E* for two years after the level of illumination was increased and the lighting and seeing conditions were improved.

A study of the original data reveals the inadequacy of conducting such an investigation for a month or two. Many hidden effects may be involved but by averaging the results for each of two years, for the same operators and operations, dependable data are obtained. There is always the possibility that the operators became more skilled, but at least they were highly skilled to begin with. Considering every detail, it is certain that the greatly improved seeing conditions markedly increased the quality and quantity of useful work done and were largely responsible even for any increase in skill if there were any. The accumulative effects of decreased strain and fatigue, of better attitude and heightened morale and of other favorable physiological effects and psychological factors apparently did not reach an optimum until the middle of the second year after the better lighting and seeing conditions were provided.

In Chapter IX we have dealt with the factor of time involved in seeing. Under ideal laboratory conditions the time required to see an object with 100-percent certainty is a matter of hundredths of a second. For example, in Fig. 36 it is about 4 hundredths of a second for a small black object on a white background at about the 100-footcandle level and about 12 hundredths of a second for a small black object on a gray background at the 10-footcandle level. Inasmuch as these values are the minimums for ideal laboratory conditions, we may conclude that seeing an object or detail under usual conditions is a matter of a tenth or tenths of a second.[20]

It is of particular interest to examine Fig. 36 and note the effect of footcandle-level upon the time required to see a black object of a given size on gray and white backgrounds, respectively. It is evident that, by increasing the level of illumination from 10 to 100 footcandles, the decrease in time required to see the object of low brightness-contrast is greatly decreased. The optimum footcandle-level for the same object of high brightness-contrast is much lower than that for the former.

Naturally, speed of seeing is associated with rate of reading[1] or rate of performance of any task of seeing. The fact that it takes time to see is basically important, but production also depends upon time lost in other ways. One needs only to observe someone performing a task involving various critical details and operations under meager light or poor lighting, to see time wasted and to be convinced that the total time required to complete the task depends upon other factors than the fractions of a second actually required for seeing. When seeing is difficult and seeing conditions are poor, the time lost in seconds, here and there throughout a complex task of seeing, may add up to a much greater total than the sum of the fractions of seconds fundamentally necessary. The operator may have to turn the object this way and that and he may have to bring his eyes close and do other things, thereby losing much time in accumulated dribbles, which would not be lost if the seeing conditions were good. Such examples are to be seen on every hand throughout the work-world. Maximal efficiency in the use of time and other human resources is extremely rare in our world of critical near-vision.

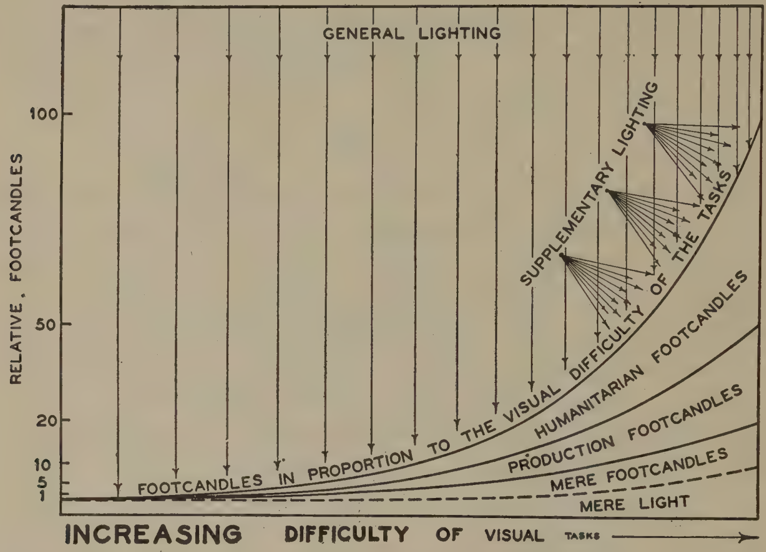


FIG. 81.—A diagrammatic view of the progress of lighting as represented by increasing footcandle-level, as dictated by the science of seeing. This not only reveals the need and provides the means for fitting the lighting to the task, but has expanded the viewpoint into the humanitarian realm of conservation of human resources.

In Fig. 38 are shown the effects of footcandle-level on the rate of performing a special task involving small details. The manual work was quite limited so that it represents a task involving seeing for the most part. It is obvious that the rate of performance increased considerably as the level of illumination increased to and beyond 50 footcandles. In this case the optimum level of illumination, even from the narrow viewpoint of production, is 50 or even 100 footcandles.

Seeing tasks vary all the way from those involving much manual work guided more or less by vision to those consisting almost entirely of seeing. From the narrow viewpoint of production, the optimum footcandle-level is greater for the latter type of task than for the former.[6] Obviously, it is greater for reading 3-point type than for reading the printed matter of this page. The footcandle-level for optimum ease of seeing is always higher than the footcandle-level for optimum production or rate of performance of a visual task. However, both are very much higher for inherently difficult visual tasks, involving critical details of inherently low visibility than for such a task as represented by this page of printed matter whose details have visibilities far above threshold for average or even poor seeing conditions. These generalizations are illustrated diagrammatically in Fig. 81.

PRODUCTION AND EASE OF SEEING

The rate of performance of a visual task or of useful work has been erroneously used as a criterion of ease of seeing or of seeing conditions. For example, speed of reading has been widely used as a criterion of ease of reading. Apparently this was accepted without proof and without a proper concept of ease of seeing. At best, speed of reading is an insensitive criterion. Furthermore, ease of seeing involves physiological effects of strain, tenseness, fatigue, etc. Without proof that speed of reading is measurably and adequately affected by these effects of seeing and other factors, there can be no justification of using it as a criterion of ease of seeing. This also applies to the rate of performance of any visual task.

As one penetrates the complex activity of seeing to an adequate depth, he finds many reasons why production of useful work or the rate of performance of a visual task cannot possibly be a sensitive or adequate measure of ease of seeing or of the price one pays in doing the work of critical seeing. We develop certain normal rates of reading or of working which are not our maximal rates. These normal rates may be somewhat influenced by making seeing easier, depending upon the initial see-level or seeing conditions. However, just as a runner may have quite a sprint left toward the end of a race, the human seeing-machine can always call on his reserve energy and abilities to overcome adverse conditions. These are reasons why the rate of performance of useful work, in many cases, is not greatly increased by high brightness-levels at which seeing is easiest.

One outstanding test will suffice to illustrate the foregoing. Reading matter was placed on a rack which could be vibrated. Subjects read for equal periods while the material was stationary and while vibrating. The level of illumination and all other seeing conditions were maintained constant. The task of reading the vibrating material was so severe that the subjects and their eyes were obviously strained and fatigued in a short time. Nevertheless, the average speed of reading for a group of subjects was only 4 percent slower when the reading matter was vibrating than when it was stationary.[1] This is a relatively slight difference for two tasks of reading which differed enormously in ease or difficulty.

Obviously the quality and quantity of performance of a visual task or useful work is affected more or less by the see-level and the seeing conditions. The magnitude of the influence depends upon the characteristics of the visual task. However, there are other factors of great importance beyond performance or production. The benefits to the human being, operating as a combination seeing- and working-machine, generally continue to increase with increases in footcandle-level or see-level far beyond the level at which production or performance may reach an optimum. This is true of the improvement of seeing conditions in part or as a whole, by any or all means.

SAFETY AND ACCIDENTS

Great strides have been made in increasing safety by reducing hazards. The efforts have been directed chiefly in campaigns against carelessness and in applications of material safeguards. Some very obvious things are done about seeing. However, beyond these is the complex realm of seeing which is involved in practically all accidents but which is not adequately understood or considered in safety activities. Actually seeing is a relatively rare word in discussions of safety and accidents and even important aspects of vision and of visibility are too generally ignored.

The annual toll of unnecessary accidents in the United States in recent years is staggering. About 50,000 persons are killed each year in the work-world and on the highways. Every 10 minutes, on the average, someone dies accidentally. Every few seconds, someone is injured. Each year about 2,000,000 persons are injured sufficiently to be unable to work for a day or more. The material loss is at least $4,000,000,000 annually.

At the present rate of accidents on the highways alone, one has little chance of escaping an accident during his lifetime. For example, of one million babies born this year, according to the present accident rate, 30,000 will be killed in their lifetime; 140,000 of them will be seriously injured; and they will be involved in 900,000 accidents. That many of these accidents involve low see-levels or poor seeing conditions is indicated by the fact that 50 percent of all highway accidents occur after dark with only 20 percent of all highway traffic involved during darkness. In other words, the accident hazard at night on the highway is several times greater during poor seeing conditions than in the daytime when they are excellent at least from the viewpoint of adequate light.

LIGHT AND SAFETY

Besides much statistical data which indicate that safety on streets and highways is much greater under the good lighting conditions of daytime than under the meager light and primitive lighting conditions of nighttime, many analyses in industrial plants show a decrease in accidents after the lighting is improved. A score of years ago statisticians of insurance companies concluded that 15 to 25 percent of all industrial accidents were due to inadequate footcandle-levels or poor lighting conditions. Certainly at that time what were considered adequate light and proper lighting were far below the standards revealed since by the science of seeing. Therefore, the estimates of 15 to 25 percent as being due to lighting deficiencies are likely to be very conservative. Unfortunately, even today insurance adjusters and statisticians are not likely to be lighting specialists, and certainly they are not seeing specialists. As a consequence, neither poor lighting nor poor seeing conditions are likely to be blamed sufficiently for accidents.

There are many reports of decreased accident-rate after the lighting has been improved. These do not necessarily involve judgments of lighting or of seeing. They are merely before-and-after statistics. For example, in an industrial plant the general illumination was increased from 2 to 20 footcandles and the accident-rate decreased 50 percent. In another, a 10 percent decrease in the number of accidents resulted when the illumination was increased from 10 to 30 footcandles and the lighting system was also of better design.

One cannot contemplate the lighting conditions prevailing in most industrial plants, in terms of light and lighting for high visibility and quick and certain seeing, without concluding that lighting and seeing conditions are involved in most accidents not due to carelessness and mechanical failure. Many illustrations in previous chapters reveal that seeing becomes easier up to and beyond a brightness-level of 100 footlamberts. This means levels of illumination of at least 100 footcandles on the visual tasks and in some cases 1000 footcandles or more. In this connection one might reflect that brightness-levels of 100 footlamberts and more are common outdoors in the daytime, even on "dull" days, where quick and certain seeing reduces the accident-rate markedly as compared with the rate at night.

In this connection the reader might turn to Figs. 29, 32, 33, 35, 36, 39 and 41. Fig. 58 reveals how visibility or see-level is considerably lower for persons with moderately subnormal vision. There is little doubt that they need more light and better lighting and seeing conditions for the same "safety-level" as persons with normal vision. It is also well to review Chapters XII and XIII which deal, respectively, with visibility and ease of seeing.

When we view seeing as a prolonged activity, we are likely to give proper weight to the accumulative effects of low visibility and poor seeing conditions. The physiological and psychological effects are real and they result in increasing strain and fatigue as the hours pass. This is also true of driving on the highways at night. It is axiomatic that accidents increase with strain and fatigue. Thus seeing, and the effects of seeing, are involved in many ways.

The advantages of adequate light and proper lighting in increasing production, decreasing spoilage, increasing ease of seeing and in heightening morale also contribute to safety. In various ways good seeing conditions pay dividends. And overall, the cost of accidents due to poor seeing conditions in loss of time and in material damage apparently is as great or even greater than the cost of providing good seeing conditions for all the tangible and intangible benefits.

SAFETY AND SPEED OF SEEING

There is a tendency to over-emphasize speed of seeing in connection with safety, just as it is over-emphasized in production. Of course, there are many accidents where split-second seeing is involved. However, as emphasized in connection with production, seeing an object is a matter of tenths of a second. In most accidents, adequate time is more generally available than adequate factors of safety in the other fundamentals of visibility. The worker or driver, or anyone else about to have an accident, is doing something else at the time. He is not expecting an accident. Much of his "sense capacity" is engaged in his task. It requires high visibility to affect that part of his sense capacity that may be available. One cannot properly judge visibility or seeing conditions after the accident when he devotes all his attention or sense capacity to the situation. This was not the condition under which the accident occurred.

In most cases, excepting those in which split-second seeing is involved, as in driving at high speed, there is plenty of time available for seeing. The trouble is caused by a deficiency in various factors which results in insufficient visibility or attention-value. A step on a stairway may not be adequately visible because of little or no contrast in brightness or color. A hazard may be concealed in a relatively dark shadow. A moving part of a machine may be too nearly of the same brightness and color as a stationary part. Everywhere there are hazards because of low visibility or inconspicuousness. The same fundamental facts and principles discussed in detail in preceding chapters apply equally to seeing for safety as they do to seeing quickly, accurately and easily.

LIGHT FOR EASY SEEING

New and extended viewpoints have arisen from the science of seeing. The footcandle-level for a given see-level is determined by the visual task as shown in Fig. 58. The enormous variation in footcandle-level necessary to make various tasks of the same visibility or see-level is illustrated in Fig. 59. It is seen that for a standard of visibility represented by 8-point type illuminated to 10 footcandles, some of the tasks require 100 footcandles and even hundreds of footcandles. For persons with average vision, which is below normal, the footcandle-levels must be increased still further. In Fig. 33 it is seen that 1000 footcandles and more are necessary to obtain high visibility in some cases. Particularly when objects or critical details are small and of low brightness-contrast, the footcandle-level must be very high to provide a visibility-level or see-level comparable to that of this printed page when illuminated by only 10 or 20 footcandles. These facts are axiomatic.

In Fig. 81 is illustrated the progress in footcandle-levels from the long era of "mere light." With more efficient gas and electric lighting, areas began to be illuminated and not merely the visual task. This era of "mere footcandles" continued for about a half century. During World War I with emphasis on production, lighting specialists began to specify "productive footcandles." However, with the growth of the science of seeing a new era of "humanitarian footcandles" was born. These footcandle-levels not only encompass the productive levels but also the higher levels for easy seeing. The higher levels of illumination are readily and efficiently obtained upon the critical visual tasks, by adding supplementary lighting to general illumination in various ways.

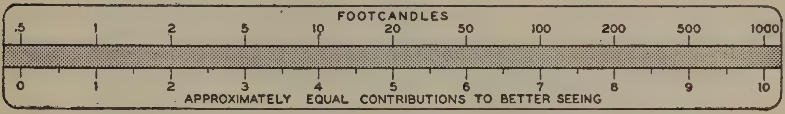


FIG. 82.—The science of seeing reveals the fundamental law that the footcandle-level must be doubled to provide an obvious and significant improvement in the effectiveness of seeing.

Many researches in seeing have established the fact that the level of illumination must be doubled to obtain an obvious or significant improvement in visibility and ease of seeing. The relation of footcandle-level to visibility and ease of seeing is approximately that shown in Fig. 82.

It is well known that any sensation, such as brightness, increases in arithmetic steps as the stimulus (in this case, footcandles) increases in geometric steps. However, various researches described in Chapter XIII have revealed that the benefits of increased visibility and ease of seeing also increase in arithmetic steps as the footcandle-level increases in geometric steps. Therefore, Fig. 83 aids in visualizing the relation of footcandle-level to footcandle-effectiveness. The diagram encompasses eight approximately equal steps in footcandle-effectiveness for nine levels of illumination—1, 2, 5, 10, 20, 50, 100, 200, 500 footcandles. Round numbers are purposely used but it will be noted that each successive step is approximately double its predecessor.

Incidentally, supplementary lighting can and should be added to the general illumination to obtain the higher levels of illumination. It is easy to obtain 100 or 500 footcandles of supplementary illumination by means of fluorescent lamps. It is not difficult to obtain 1000 footcandles or more by means of tungsten-filament lamps in projectors. Thus high footcandle-levels can be obtained on critical visual tasks without a great increase in cost. Wherever practicable the general illumination should be at least one-tenth, and preferably one-fifth, of the total illumination on the visual task. Even smaller ratios are sometimes desirable but the best ratio depends upon the specific task and the reflection-factors of its surroundings and those in the entire visual field.

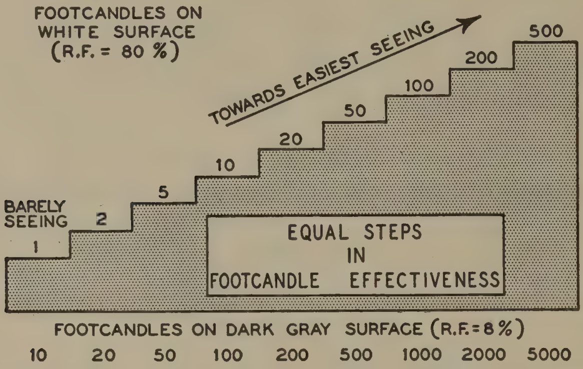


FIG. 83.—Eight practical and significant steps in footcandle-level above one footcandle. Inasmuch as the purpose of illumination is to produce brightness, footcandle-levels must be considered in connection with reflection-factors. The upper scale is for a white surface of 80-percent reflection-factor. Therefore, on the lower scale for a gray surface of 8-percent reflection-factor, the footcandle values are ten times greater.

SPECIFYING FOOTCANDLE-LEVELS

It is seen that a scientific specification of footcandles upon a given critical task of seeing is a matter of measuring visibility and of deciding upon a standard visibility-level or see-level. Various suggestions and examples are presented in Chapter XII. For those who are unable to make such measurements, recommendations are available by technical organizations. These are generally conservative and they necessarily lag behind progress in light-production and its effect upon foremost lighting practices. Lighting codes are continually being revised upward and their specifications of light and lighting are beginning to be based upon the science of seeing.

More than a decade ago the author tried to reduce to words some recommendations which would be helpful in themselves and which took into account various characteristics of visual tasks. These recommendations are very conservative from the viewpoints of visibility and ease of seeing.

100 Footcandles or More—For very severe and prolonged tasks, such as fine needlework, fine engraving, fine pen-work, fine assembly, sewing on dark goods and discrimination of fine details of low contrast, as in inspection.

50 to 100 Footcandles—For severe and prolonged tasks, such as proofreading, drafting, difficult reading, watch repairing, fine machine-work, average sewing and other needlework.

20 to 50 Footcandles—For moderately critical and prolonged tasks, such as clerical work, ordinary reading, common benchwork and average sewing and other needlework on light goods.

10 to 20 Footcandles—For moderate and prolonged tasks of office and factory and when not prolonged, ordinary reading and sewing on light goods.

5 to 10 Footcandles—For visually controlled work in which seeing is important, but more or less interrupted or casual, and not involving discrimination of fine details or low contrasts.

1 to 5 Footcandles—Inadequate for most critical seeing. Satisfactory for perceiving larger objects and for casual or conversational seeing.

The most recent recommended practice of industrial lighting, approved by the American Engineering Standards Association and reprinted by the U. S. Department of Labor, covers a range of general illumination up to 50 footcandles and, with the addition of supplementary lighting, up to 100 footcandles. These are minimum footcandle recommendations in service. Even with these ranges, as is true of the author's general recommendations, those who must perform the more critical tasks of seeing are not as well taken care of as those who are more fortunately confronted with the easier tasks, such as reading this printed page. However, a good beginning has been made in placing footcandle recommendations on a scientific basis. The lighting or seeing specialist can fit the footcandle-level and the character of the lighting to each specific task by means of visibility measurements. He will find that hundreds and even thousands of footcandles are desirable in many cases and such levels of illumination on specific tasks are no longer impracticable or prohibitive in cost.

Everywhere one will find visual tasks varying enormously in visibility or inherent difficulty. In Chapter XII we have discussed this aspect in detail. Here it may suffice merely to emphasize some of these differences again. Let us take the relatively easy task of reading. By comparison, such a task as sewing on dark goods may require 100 or 500 footcandles for a visibility-level equal to this printed matter illuminated to 10 footcandles.

When someone carelessly states that 10 footcandles are enough for reading, a flood of questions demands answers.

What kind of eyes are involved? Are they young or old? Is that specification based upon normal vision or is it for persons with average vision or poorest vision in an office or classroom, in the home or in the work-world?

What kind of reading matter is involved? Is it small type or large type? Is the printing good or bad? Are poor duplicated materials to be read? Are shorthand notes, faint typing, and carbon copies included?

What kind of a criterion is the recommendation founded upon? Does it arise from the narrow viewpoint of speed of reading which is an inadequate, insensitive criterion of ease of seeing? Does it arise from considerations of ease of seeing?

What kind of performance is involved or demanded? Is the task to be prolonged for hours and days? Is accuracy a vital factor?

What humanitarian aspects of seeing are taken into account? Are strain, fatigue and the conservation of eyesight and other human resources considered?

What costs are involved in the specifications? Does the monetary cost of good seeing conditions outweigh the costs to the reader? Shall we be content to ignore the enormous advances in light production and commensurate decrease in the cost of light, for example, and be the victims of ignorance and habit? Or shall we be the beneficiaries of modern science by reducing the burdens of human eyes and of human seeing-machines?

These and other questions arise not only for reading but for all prolonged tasks of critical seeing. Visibility measurements reveal that even for reading, the range of footcandles for equal visibility of different materials and for different visual efficiencies and requirements extends from the 10-footcandle to the 100-footcandle level and beyond. The brightness-level for easiest seeing is greater than 100 footlamberts and apparently two or three times as great.

In connection with reading, let us examine briefly the lettering in run-of-the-mine comic books which children read by the hour. In Chapter XII we have discussed how visibility (RV) measurements can be interpreted directly in terms of "equivalent type-size" and also "footcandles for equal visibility." Twenty-four specimens of hand-lettering selected at random varied in equivalent type-size from less than 4-point to about 8-point type with the average being equivalent to less than 6-point type. Such type-sizes in school books and in other reading matter for children would be roundly condemned. Choosing for children a conservative standard of visibility, or see-level, represented by 12-point type illuminated to a level of 20 footcandles, we found that the footcandles for equal visibility of these hand-lettered specimens varied from a minimum of 40 footcandles to a maximum of 1500 footcandles. The latter is due somewhat to the poor lettering and printing but largely to the inexcusable use of a colored background which greatly reduced the brightness-contrast. The average footcandles necessary for equal visibility of the 24 specimens was 150 footcandles.

Such analyses rob such a question—How much light is desirable for reading?—of its apparent simplicity and also make a simple sweeping answer appear naive if not ridiculous. The same kind of analyses apply to all other tasks, which unfortunately cannot be so easily described or visualized. However, their visibilities can be measured and lighting and seeing conditions can be specified on the same rational basis.

CHAPTER XVII

One Hundred Questions

From many questions commonly asked, the author has selected representative ones and has answered them briefly. Obviously space does not permit detailed discussion of each question. Most of the questions may appear simple but in reality many of them involve a complexity of facts and factors. It is presumed that the reader will view these answers in this light. If in doubt he will find in preceding chapters the reasons underlying most of the brief answers given here.

EYESIGHT AND VISION

1. *What is normal vision?*

Certain tests have evolved from research and experience. For example, if a person can recognize test-objects of appropriate visual size, such as the letters in the top line of the A.M.A. Test-Chart at a distance of 20 feet, he has average normal vision. A small percentage has better vision than this but a large percentage has some degree of subnormal vision which is expressed in several ways. Eyes should be tested for near-vision as well as for distant-vision.

2. *What is the boundary between distant-vision and near-vision?*

There is no definite boundary. When viewing objects at a distance of 20 feet or more, normal eyes are considered to be relaxed. When the eyes are focused upon nearby objects the muscles of convergence and accommodation are under some degree of tension. Most near-vision tasks are performed within arm's reach.

3. *What is a diopter?*

It is the unit in which the power of a lens is expressed. The power of a lens is the reciprocal of its focal length in meters. A convex lens having a focal length of one meter has a power of one diopter. The minus sign is used to express the power of concave lenses.

4. *What is myopia?*

It is nearsightedness. Actually the image of a distant object comes to a focus in front of the retina. By the use of a concave lens of proper power the position of the image is moved backward to the retina.

5. *What is hyperopia?*

It is farsightedness. Actually the image of a distant object comes to a focus behind the retina. By the use of a convex lens of proper power the position of the image is moved forward to the retina.

6. *Why are old persons generally farsighted?*

On reaching middle age, many persons begin to lose some of the power of accommodation. Nearby objects do not appear well defined. This kind of farsightedness is known as presbyopia. By adding convex eyeglasses this inability is compensated for, and objects within arm's length can be seen distinctly.

7. *Are bifocal eyeglasses completely satisfactory?*

After one gets used to them they are quite satisfactory for the performance of many tasks of near-vision, such as reading this page, when the eyes and the work are more or less fixed in relation to each other. For some tasks which require one to see nearby objects in the upper part of the visual field, a pair of glasses entirely for close work is generally desirable.

8. *What is astigmatism?*

This common defect of vision is due to a distortion of the curvature of the cornea or of the lens of the eye. It is compensated for by a cylindrical lens of proper power placed in the proper axial position.

9. *Do eyeglasses really correct eye-defects?*

They do not actually correct them but they compensate for certain defects of the optical system of the eye. In this sense they correct incorrect vision. Eyeglasses are also prescribed for correcting certain other defects such as imperfect muscular control of the eyes.

10. *Why are contact lenses used?*

These are placed directly in contact with the cornea or front surface of the eyeball. Their chief purpose is to compensate for a distorted cornea which cannot be perfectly compensated by ordinary eyeglasses. Actors and others sometimes wear them because they are not noticeable.

11. *Who invented eyeglasses?*

Marco Polo saw eyeglasses in China in 1275. Roger Bacon in the same century revealed how glass bends or refracts light rays. He described a reading glass which made letters "appear far better and larger" and recommended it as "useful to old men and to those that have weak eyes." Galileo in about 1600 greatly extended the visible heavens by means of telescopes. Not long after, Leeuwenhoek with his microscopes greatly extended the visible world of minute things. Benjamin Franklin is said to have invented, and was the first to wear, bifocal glasses.

12. *What is the difference between an ophthalmologist and an optometrist?*

The ophthalmologist (or oculist) is a member of the medical profession specializing in various phases of eye-care including eye-testing and the prescription of eyeglasses. The optometrist is not licensed to practice medicine but is licensed to test eyes, prescribe eyeglasses and practice physical therapy. The optician makes glasses according to the prescriptions.

13. *What is meant by threshold size?*

The threshold size of an object is the minimum size that is barely visible under given seeing conditions. Similarly, threshold brightness or threshold contrast is the minimum perceptible under given seeing conditions. Threshold sound is the minimum that is audible under given sound conditions.

14. *Is reading in bed harmful to the eyes?*

If one is in a sitting position and provided there is plenty of light on the printed page and the general surroundings are illuminated to a fair degree, reading in bed should not be harmful.

15. *Can one see better outdoors at night without eyeglasses?*

This is often true at low brightness-levels. Eyeglasses commonly absorb nearly ten percent of the light. This is enough to reduce the visibility of an object below threshold which, without glasses, might be at least barely visible. Visual acuity is not generally important at very low brightness-levels; therefore, neither are eyeglasses.

16. *Do Negroes have better eyesight than whites?*

According to a 1943 report of the U. S. Selective Service System, rejections for military service on account of eyesight constituted about 12 per cent of all rejections. The rejection rate for this cause was about twice as great for whites as for Negroes. It appears reasonable that this difference is due in part, at least, to the generally greater use of the eyes in near-vision tasks by whites. It is significant that only relatively young men were involved and that their vision was not a cause of rejection if it were as low as 20/100 in each eye without glasses, provided it was correctable to 20/40 with glasses.

17. *What percentage of man's usefulness is due to eyesight?*

From an overall viewpoint the progress of civilization is largely due to mind aided by the senses. Vision is our most important educative and educated sense. It far outranks our other senses in usefulness and is estimated to be responsible for 75 to 90 percent of the usefulness of most civilized adults.

18. *How many blind persons are there in the United States of America?*

One source of statistics recently stated that there are 140,000 totally blind persons. However, it is estimated that 2,000,000 persons have only 20/200 vision which is considered to be legal blindness in some countries. This means that they can barely recognize the last line of the A.M.A. Test-Chart at a distance of 20 feet instead of at 200 feet as can persons with 20/20 or average normal vision.

19. *Are eyes of old persons intolerant of high levels of illumination?*

There are many instances when old persons seem to be less conscious of light and of glare than younger persons. Possibly life has taught them to accept hardship and even abuse. There are certain facts which indicate that old eyes should need higher levels of illumination than young eyes. In fact, one can render valuable service to many old persons by supplying them with an unusually high level of illumination. If their eyes have cataracts, try concentrating the light only on the visual task and shield the eyes from all other light.

20. *Does a deficiency of Vitamin A affect vision?*

It does, but this is of practical importance only in night vision. A deficiency reduces the ability to see differences in brightness at low brightness-levels. However, some researches indicate that most of us obtain sufficient Vitamin A in our ordinary diets for satisfactory night vision.

21. *Are eye-exercises beneficial?*

Various unproved claims have been made by proponents of eye-exercises, even to the extent that they are sometimes promoted as a cure-all. However, this does not justify the extreme opposite do-nothing attitude. If we fully appreciate the prolonged strain of eye-muscles in focusing the eyes upon close work, we can scarcely avoid the conclusion that moderate systematic eye-exercises might be helpful. We exercise our legs and our entire bodies. Why not relax and exercise the eyes by exercises involving distant-vision?

22. *Why do some light-sources appear to flicker when one is not looking directly at them?*

The peripheral region of the retina is more sensitive to flicker and other changes in brightness, such as that due to moving objects, than the central region. This is an excellent dual-purpose. Critical seeing is done best by direct vision but our safety, for example, is somewhat dependent upon indirect vision.

LIGHT AND BRIGHTNESS

23. *What is the basic unit for measuring light?*

The standard candle is an arbitrary standard maintained by appropriate governmental agencies. The luminous intensity of the flame of an ordinary vertical candle, about one inch in diameter, is approximately one candlepower in a horizontal direction.

24. *What is a footcandle?*

Intensity (or level) of illumination on a surface is measured in terms of the footcandle. Imagine a light-source and a surface perpendicular to a line drawn from it to the light-source. At a distance of one foot from a light-source of one candlepower the level of illumination of the surface is one footcandle. At 10 feet from a source of 100 candlepower the illumination is one footcandle. The intensity of illumination generally varies inversely as the square of the distance from the source of light. This fact is commonly ignored by users of light and eyes.

25. *What is the inverse square law?*

It is a common law of geometry applicable to light, heat, sound and other cases where energy or something else spreads out after leaving its source. A cone of water spray has a certain solid angle. The cross-section of the cone increases as the square of the distance but the total amount of water passing through each cross-section, regardless of its area, remains constant. Therefore, the density of the spray per unit of area is inversely proportional to the square of the distance from the source. In a similar way the intensity of illumination—the footcandles—from a given light-source (of relatively small dimensions) is found by dividing the candlepower of the source by the square of the distance in feet.

26. *What is a lumen of light?*

This is the unit of the flow of light from a source. A light-source of one candlepower in all directions radiates a total of 4π lumens. Draw a sphere with a light-source at the center. If the radius is one foot the area of this sphere is 4π square feet. One lumen of light illuminates each square foot of this imaginary sphere. One lumen per square foot is also an intensity of illumination of one footcandle. Viewed another way, the inner surface of this imaginary sphere is one foot distant from the light-source of one candlepower. Therefore, the illumination at this distance is one footcandle.

27. *What is brightness?*

Radiant energy of a certain range of wavelengths, coming to the eyes from this page or other object, produces sensations of brightness and of color, when the energy reaches our visual sense. Analogously, energy in the form of a succession of waves in the air, for example, produces the sensations of sound and pitch when it reaches our auditory sense. Both the visual and auditory senses are receiving sets, each for its own form of energy and for its own range of wavelengths or frequencies.

28. *How is brightness measured?*

It is measured by comparing it with a controllable brightness whose value is known in terms of an arbitrary unit. Analogously, we weigh something in terms of a controllable weight whose value is known in terms of arbitrary units such as the ounce, pound and ton. The unit is selected for convenience. The brightnesses of light-sources are commonly measured in terms of candles per square inch, and of reflecting surfaces in terms of footlamberts. The brightness of the former is about 452 times as great as the latter.

29. *What is the minimum difference in brightness between two surfaces that is barely discernible?*

At ordinary brightness-levels most persons can distinguish a brightness-difference of less than two percent. At a brightness-level of 0.01 footlambert, common on highways at night, two persons may differ by 100 percent in their ability to discern brightness-difference even though their vision is rated the same in visual acuity. One may barely discern a brightness-difference of 30 percent while the other may be able to discern a difference of 15 percent. Contrast-sensitivity is far more important in seeing at low brightness-levels than visual acuity.

30. *What is the difference between a footcandle and a footlambert?*

The former is a unit of intensity of illumination and the latter is a unit of brightness. If the diffuse reflection-factor of a surface were 100 percent, each footcandle would produce a brightness of one footlambert. Actually each footcandle produces a fraction of a footlambert equal to the diffuse reflection-factor of the surface illuminated.

31. *Why not reduce the subject of brightness to simpler terms?*

The footlambert and other brightness units are just as simple as the footcandle and other terms. Simplification is merely a matter of understanding them and becoming used to them. A footlambert is more obvious than a footcandle. We actually see brightness but not footcandles. The same footcandles on a dark coat sleeve as on a projecting white shirt sleeve produce two greatly different brightnesses. Therefore, is not the common footcandle more confusing and less straightforward than the footlambert?

32. *What is the difference between candlepower and footcandles?*

Candlepower applies to a source of light from which light may be considered to flow as from a hose or a lawn-sprinkler. Light-sources are now rated in lumens. A light-source of one candlepower in all directions emits 4π or 12.57 lumens of light. The footcandle is a measure of the intensity of the "rain" of light on a surface or of the intensity of illumination. Inasmuch as light spreads out by being radiated in various directions, the footcandles upon a surface decrease rapidly as the distance from the source increases. Actually the level of illumination decreases inversely as the square of the distance from the light-source.

33. *At what distance from a light-source is the inverse square law valid?*

It holds accurately when the distance is greater than ten times the maximum dimension of the light-source. The error is not too great for many practical purposes when the distance is only five times the maximum dimension of the light-source or area which emits light.

34. *What is meant by the luminous efficiency of an electric light-source?*

By measuring the total light in lumens which it radiates in all directions and also the watts used by the light-source, the luminous efficiency can be expressed in lumens per watt. In other words, the efficiency of a light-source is determined by the amount of light produced by each watt of electric power.

35. *What is meant by cool light?*

Radiant energy of a certain range of wavelengths is light in the sense that it causes the sensations of brightness and color. This socalled visible energy is generally accompanied by invisible radiant energy, known as ultraviolet and infrared energy. The amount of total radiant energy per footcandle depends upon the light-source. The total energy per footcandle from a tungsten-filament lamp is about four or five times that from white and daylight fluorescent lamps. The light from these fluorescent lamps is about as cool as light from the sun and sky.

36. *Is the infrared energy from light-sources harmful to the eyes?*

There is no known harmful effect of infrared energy in quantities associated with artificial light as used for lighting purposes. Even infrared energy of very much greater intensities, as experienced by workers in steel mills and boiler rooms, has not been proved to be generally harmful to the eyes.

37. *Is the ultraviolet energy from light-sources harmful?*

Ultraviolet energy commonly accompanies light from artificial sources. It is so abundant in sunlight that it prevents and cures rickets, kills germs, and probably bestows other health benefits. No reputable manufacturer would supply light-sources for general use without being certain that the ultraviolet energy was confined to the spectral range of sunlight and in quantities which would not harm the eyes exposed to the lighting for long periods. However, it is one of the future objectives of lighting to provide sufficient ultraviolet energy, but safe in quantity and spectral character, for health along with light for seeing. This is just another aspect of bringing the outdoors indoors and even in improving upon it if possible.

LIGHT AND COLOR

38. *What is white light?*

If a white or neutral gray surface appears colorless, it is said to be illuminated by white light. Noon sunlight on a clear day is approximately white. By mixing three or more properly chosen spectral colors in proper proportions, white light can be obtained. However, to fulfill all the practical purposes of a white light, the illuminant must have a continuous spectrum and the spectral distribution of energy throughout this range must be fairly uniform.

39. *Which gives the better light, "daylight" or "white" fluorescent lamps?*

A footcandle from one is no better than a footcandle from the other. Each is chosen for a particular purpose on the basis of its color. The light from a daylight fluorescent lamp is about the color of average daylight which is approximately white. The light from the white fluorescent lamp is actually yellowish white and, being less "cold" than average daylight, is widely used as a compromise in color and in psychological effect between natural daylight and artificial light of the past.

40. *What illuminant or color of light is best for seeing?*

Where the appearance or discrimination of colored materials is not involved, no illuminant suitable for general lighting purposes has any advantage over another by virtue of its color or spectral character. A strictly monochromatic light, such as sodium light, has an advantage in seeing very small details near the threshold in size.

41. *What is color?*

It is a sensation which depends upon the spectral character of the light, the selective reflection (or transmission) of the object, and the response of the visual sense to the various frequencies or wavelengths of the radiant energy reaching it. Inasmuch as the selective reflection (or transmission) of a given object is fixed, and inasmuch as normal color-vision does not vary markedly, the actual color of an object as we see it depends upon the light illuminating the object.

42. *What are the distinctly different colors?*

They are red, yellow, green and blue. In the broadest sense, white and black must be included. In all other colors two of the foregoing colors are seen. For example, in orange one sees both yellow and red; in purple one sees blue and red; in violet one sees blue and a suggestion of red; in gray one sees both black and white.

43. *How many colors are there?*

We can see at least 150 distinctly different hues included in the spectrum and in the series of purples which do not exist in the spectrum. But hue is only one component of color. Each hue can be mixed with white to produce a series of tints. In the case of pigments each of these tints can in turn be mixed with black to produce a series of shades. Even if we consider only an average of 10 tints of each of 150 hues, and an average of only 10 shades of each tint, we have 15,000 different colors. But we can still obtain a very extensive series of shades of each tint by varying the brightness of each throughout an enormous range of intensity of illumination. Therefore, in a broad and absolute sense the number of colors, distinctly different in hue, saturation and brightness, totals uncounted millions.

44. *Is green easy on the eyes?*

There is no evidence that it is easier on the eyes than grays or many other colors. However, colors have psychological powers. A color-scheme of greens may be "neutral" or "cool" depending upon the actual hue, saturation and brightness. Probably its attributes have largely arisen from its widespread prominence in natural landscapes. However, green light which illuminates everything indiscriminately is quite another matter. Human skin and other familiar surfaces may be quite unsatisfactory in appearance—even repugnant. No acceptable criterion has revealed that this page is easier to read under greenish light than under any ordinary natural or artificial light.

45. *Is there any advantage in using yellow glasses for reading at night?*

There is actually a disadvantage because they reduce the visibility of the printed matter as definitely as by reducing the brightness of the page in some other manner such as moving farther from the reading lamp or otherwise reducing the level of illumination on the reading matter.

46. *Should color-blind persons drive automobiles?*

Color-blindness is commonly a matter of degree. It has been widely broadcast that four percent of adult males and one or two percent of adult females are color-blind. Apparently this difference is due in part to more training and interest in color on the part of women. However, of great practical interest is the fact that only a few persons in each million of adults cannot distinguish a difference between red and green traffic signals. Even these negligible few can be aided by the position of the colored traffic lights.

47. *Does any illuminant penetrate fog better than others?*

In this respect no common illuminant has any appreciable or practical advantage over others. Fog consists of particles too large to transmit or to scatter light of various colors or wavelengths selectively to any practical extent. This is demonstrated by the fact that common light-sources in distant street lamps, for example, seen through fog do not appear appreciably altered in color.

DAYLIGHT OUTDOORS AND INDOORS

48. *What is the candlepower of the sun?*

The maximum level of illumination on a mountain top is about 10,000 footcandles. It is the result of the candlepower of the sun divided by the square of the distance from the sun in feet. Therefore, the candlepower of the sun is equal to 10,000 times the square of the distance in feet. The distance is about 93,000,000 miles or about 500 billion feet. The square of this latter figure is 250,000 billion billion which must be multiplied by 10,000. Therefore, the sun is approximately 2.5 billion billion billion candlepower or, simply, 25×10^{26} candlepower.

49. *Why is daylight rather colorless?*

Probably this is due to the fact that our visual sense evolved throughout the course of eons to utilize daylight most efficiently. It is natural that eons of evolution and adaptation of the visual sense have resulted in average daylight appearing practically white or colorless. Skylight is definitely bluish, as is demonstrated by a shadow on a white surface on a clear day.

50. *Why is daylight the perfect light for working with color?*

In this respect it is far from perfect. It various greatly in spectral character with the time of the day and with the point of the compass. In the Northern Hemisphere north light has been generally used for color work because it is less variable in intensity. However, it varies from a very bluish white when the sky is clear to practically white when the sky is overcast. When there are sunlit clouds in the north, the light is practically that of sunlight which varies from white at midday to a yellowish white or even a deep red-orange tint near sunrise and sunset. Much progress has been made toward duplicating any satisfactory quality of daylight by artificial means.

51. *Why is the sky blue?*

Skylight is selectively scattered sunlight. The molecules of air are comparable in size with the wavelengths of light. As a consequence the violet and blue components of sunlight, having relatively shorter wavelengths, are scattered more than the yellow, orange and red components. If a field were strewn with stumps one or two feet high, in crossing this field young boys would be scattered more than men with longer legs.

52. *Why is the setting sun red?*

To reach us the light must pass through a much greater mass of smoke-laden air when the sun is near the horizon than during midday. The air selectively absorbs the violet and blue rays more than the yellow, orange and red rays. Selective scattering of light also plays a part. Note the shadow cast on a white surface by a puff of smoke. In the sunlight it has a ruddy tinge. Also note the bluish tint of the light selectively scattered by the smoke curling from the burning end of a cigar. At the moist end the smoke appears white. Water vapor has condensed around the small smoke particles and they, as in the case of fog, are too large to selectively scatter light to any appreciable extent.

53. *What kind of lighting is daylighting outdoors?*

It ranges from one extreme, equivalent to totally indirect lighting when the sky is completely overcast, to a combination of direct and indirect lighting on sunny days. On an average clear day the direct light from the sun contributes about four times as much light to the earth's surface as the sky does.

54. *Are sunglasses necessary?*

They may not be actually necessary for persons with normal vision. They reduce the strain and fatigue which results from squinting in an effort to lessen the glare from large areas of bright snow, sand or pavement. They should not be worn indoors or for driving at night. They should be of good optical quality.

55. *Is not daylight superior to artificial light in a school classroom?*

In such buildings architects have done as well as possible with natural light by providing large window-areas on one side of relatively small rooms. However, the distribution of daylight throughout the room is far from uniform. If a classroom were illuminated in a similar manner by artificial light, the lighting would generally be considered quite unsatisfactory. In cloudy climates, and during much of the time in winter in the higher latitudes, a good artificial lighting system is often necessary and generally desirable much of the time, even during the day.

56. *Will not daylight always have the advantage of costing nothing?*

Daylight costs nothing outdoors. Indoors its cost is represented by the cost of windows and other skylights such as those of monitor and sawtooth roofs. To this must be added the overall cost of wasted rental space in providing light-courts and set-backs of the upper stories of skyscrapers. Maintenance of these, the loss of heat, and other factors are chargeable to daylight. Failing at least once a day, a part of the cost of a standby artificial lighting system is also chargeable to daylight. We want windows to look out of but the "daylight habit" acquired in bygone eras of inadequate and relatively inefficient light-sources is now responsible for many costly and questionable practices. The inadequacy of daylight indoors is exemplified by the widespread use of artificial light in the daytime in stores, offices, factories and elsewhere in congested areas.

57. *Why is it impossible to provide as good seeing conditions indoors as outdoors?*

The same seeing conditions can be produced indoors with artificial light as are found outdoors in the daytime. There is a widespread belief that there is something mysterious, unfathomable or even unapproachable about natural lighting outdoors. This is not true. The seeing conditions outdoors are the result of the brightness-level and the distribution of brightness and color. They can be analyzed in any and all cases and can generally be improved upon indoors for prolonged critical seeing. The chief difficulty in accomplishing this is to supply the high levels of illumination which will produce the necessary brightnesses of objects and surfaces of low reflection-factors.

58. *Why does artificial lighting indoors so often appear dim and unsatisfactory in the daytime?*

Usually it is relatively dim and inadequate. In restaurants and other places where prolonged critical seeing is not involved, it would be justifiable to provide more artificial light in the daytime than at night. This would reduce the great difference in adaptation. If, in offices and other work-places, artificial lighting is adequate for prolonged critical seeing, it will compete favorably with the daylight in most interiors and will not appear dim and unsatisfactory.

59. *Does the lesser accident rate on highways during the day prove the superiority of daylight?*

It indicates that seeing on the highway is relatively better under high levels of illumination than under the conditions at night. No artificial lighting can ever be superior to full daylight on highways. Even the best automobile headlamps cannot provide adequately safe, certain and easy seeing, particularly on two-way highways. At best they represent an evolutionary stage which should be followed by a general illumination of highways by such means as appropriate equipment on poles.

60. *Why do we not see color outdoors at night?*

At the low brightness-levels outdoors at night, color-vision becomes practically inoperative. Receptors in the retina, commonly known as the "rods," take over the task of seeing at brightness-levels lower than 0.01 or 0.001 footlambert and the socalled "cones" which are responsible for color-vision become relatively insensitive. Actually under laboratory conditions, colors are discernible at very much lower levels of brightness than the foregoing.

LIGHT AND LIGHTING

61. *What is the ideal lighting system?*

By adding supplementary lighting to the general lighting the maximum control of light for seeing is possible. The former can be fitted to each specific task to increase visibility and ease of seeing while the general illumination serves these same purposes and contributes something to safety and much toward good seeing conditions.

62. *Why is indirect lighting ideal?*

It is not ideal. It is a great improvement over direct lighting with its relatively bright sources or lighting equipment and their high brightness-ratios with the relatively dark ceiling. Generally glare is reduced by indirect lighting but not eliminated. The broad expanse of illuminated ceiling is by far the brightest area in the room. This is undesirable. The ideal can be approached by adding suitable supplementary lighting fitted to the seeing tasks.

63. *What are the advantages of localized light on a visual task?*

If this is in addition to adequate general illumination there are various decided advantages. High levels of illumination can be obtained efficiently and the light can be properly directed and diffused to suit the task. It is often advantageous to be able to orient an object in respect to the local light-source or to the dominant supplementary light.

64. *What is meant by balanced lighting?*

This is a useful description of a combination of direct and indirect components in lighting or of supplementary and general lighting. A proper balance between these, taking into account the brightnesses resulting from footcandles and diffuse reflection-factors, is a very important step toward the ideal use of light for seeing.

65. *What is the maximum permissible brightness in the visual field?*

This depends upon a variety of external, visual and retinal factors. The sun, whose brightness is 1,000,000 candles per square inch is overwhelmingly too bright. A sunlit cloud, whose brightness may be 20 candles per square inch can scarcely be considered to be directly harmful. Excepting in very large interiors such a brightness is generally undesirable indoors under ordinary levels of illumination and amid the usual brightness conditions. The permissible brightness of a light-source or other bright area depends largely upon its candlepower toward the eye, its distance from the eye, its position in the visual field, its brightness-ratio with its background, and the general level of illumination or of brightness.

66. *Can a complete artificial lighting system be supplied on a blueprint?*

This is possible in simple cases, such as a classroom in a school where no supplementary lighting is to be used excepting on blackboards whose locations are known. General lighting for stores, offices and factories can be laid out on a sheet of paper. However, where supplementary lighting is to be used at machines and other work-places, for example in a factory, the lighting specialist must study the various visual tasks and locations in order to advise most satisfactorily. The doctor must personally examine the patient if the diagnosis is to be thorough and the treatment adequate.

67. *Does a glossy white paint reflect more light than dull or non-glossy white?*

The light specularly reflected from glossy white paint is an insignificant part of the total reflected light. The amount of light diffusely reflected by the white pigment bears no relation to the character of the surface. It depends upon the purity of the white pigment and of the vehicle or binder. A dull white paint is just as likely to reflect more light than a glossy one as it is to reflect less.

68. *Should light come over the left shoulder?*

This is a specification which arose from considerations of right-handed persons so that, when writing, the hand does not cast an annoying shadow. When reading, for example, light coming from the right is just as satisfactory as from the left. Daylight windows on the left side of a school classroom are a concession to the great majority of right-handed pupils. Obviously the left-handed minority is ignored.

69. *What is the best light for reading?*

Any common illuminant is satisfactory, provided there is adequate light upon the reading matter from the right direction to avoid glare from the source and from specularly reflected images from glossy paper. Also, the immediate surroundings should not be relatively too dark. The reading lamp on a desk should not be directly in front. We would not use a floor lamp this way when reading at night at home. This also applies to the local reading lamps in a public library, where properly shaded fluorescent lamps can be placed at intervals across the reading tables. Thus the reader may have a shaded light-source on either side of him or even on both sides.

70. *Are the spotlights which are sold for reading in bed satisfactory?*

They are not satisfactory if they are used alone. Then the surroundings are entirely too dark for comfortable and easy seeing. In fact, the use of such a spotlight without any other lighting in the room is primitive lighting at its worst.

71. *Should lighting fixtures be hung as high as possible?*

There are many exceptions, but for general lighting in large interiors of the work-world, fixtures should be hung as high as is practicable. Glare from a given lighting fixture decreases as its angular distance from the normal line of vision increases. It also decreases approximately as the square of its linear distance from the eye.

72. *How much light should be provided by a portable lamp for reading?*

A portable lamp for reading should provide at least 25 or 30 footcandles on this page at a distance of about two feet from the lamp. At twice this distance the level of illumination is only about one-fourth or about 7 footcandles. On the floor 10 feet away the illumination dwindles to one-hundredth or only a fraction of a footcandle. This socalled inverse square law is very important. The very rapid decrease of illumination with distance is one of the major lessons to be learned about the everyday use of light.

73. *Why do the socalled sight-saving portable lamps waste so much light on the ceiling?*

The light that is emitted upward from the open top of the shade is not wasted. It is a guarantee against the primitively poor seeing conditions which would result if only downward light were provided. The modern sight-saving lamps provide a combination of general illumination with direct, supplementary or localized light.

74. *During rest-periods of 15 minutes should the 50-footcandle level be reduced to a lower level?*

It requires about 10 minutes to become fully adapted to such a change; therefore, a reduction is impracticable from this viewpoint. The 50-footcandle level of illumination is not in itself fatiguing. Relaxation during a rest-period is largely a matter of relieving the strain upon eye-muscles and the general muscular, neural and mental tenseness. These results can be accomplished without disturbing the adaptation to brightness.

75. *Which is preferable, 50 footcandles of general lighting or 20 footcandles plus good local lighting?*

There are many critical tasks of seeing which require far more than 50 footcandles. Therefore, in many cases one might well accept 20 footcandles of general illumination in order to be free to provide much higher levels of localized light fitted to the tasks. Depending on the character of the task, the localized illumination might be 100, 200 and in some cases 500 footcandles or more.

76. *How can the utilization factor of a lighting system be greater than 100 percent?*

Utilization factor is empirically defined as the ratio of the total lumens reaching a horizontal work-plane, for example, to the total lumens emitted by the light-sources of a general lighting system. It can exceed 100 percent if the floor and other areas have high reflection-factors. These areas reflect some of the light upward which is reflected again by the ceiling and walls to the work-plane. Thus to some extent the light "piles up" on the work-plane. In a room with white ceiling, walls and floor, the lumens on the floor area can exceed those emitted by the light-sources by several hundred percent. This may seem like getting something for nothing, but it is merely the result of initially reflecting much of the light instead of absorbing most of it. Actually the rate of absorption of light in a room is equal to the rate of emission of light by the light-sources in the room.

77. *Will built-in lighting do away with portable lamps?*

When and where artificial lighting is fully appreciated as an essential aid to seeing the tendency to install localized lighting permanently, as is done with general lighting, will increase. This applies to machines and work-places everywhere when these are fixed in position. However, in some rooms in the home and in some other places, the mobility of portable lamps is a great asset. They allow freedom in the arrangement of furniture and in the choice of work-places. In a very important matter they make the renter independent of the landlord.

78. *How can one judge the satisfactoriness of a lighting system?*

Gross defects such as unshaded light-sources in the visual field, harsh and dark shadows, dark surroundings and meager light are obvious to anyone conscious of their effects upon visibility and ease of seeing. However, if there are no gross defects, good judgment is based upon knowledge and experience which in turn are based upon measurements of footcandles, brightness and visibility. In addition there are those aspects of the science of seeing which, as in the science of medicine, can only be established by tedious researches under laboratory conditions.

79. *If a lighting installation appears to be satisfactory, why do the workers complain?*

There is a vast difference between merely looking at a lighting installation and actually performing tasks of critical seeing. Conditions which appear to be benign for conversation and casual seeing are often very unsatisfactory for the performance of critical seeing. This is true of every aspect of lighting and of seeing conditions, such as glare, level of illumination, brightness-level, and brightness-distribution.

80. *What is a kilowatt-hour?*

It is the common unit of electrical energy. If 1000 watts are used for one hour, the total electrical energy used is 1000 watt-hours or one kilowatt-hour. If a 100-watt lamp is used for 10 hours the total energy consumed is 1000 watt-hours or one kilowatt-hour. The cost of a kilowatt-hour to the user varies with various factors but it is commonly only a few cents at most. At a 3-cent rate, a 100-watt lamp costs 3 cents to operate 10 hours and a 300-watt lamp costs less than one cent per hour to operate.

LIGHT, VISIBILITY AND SEEING

81. *What is the difference between vision and seeing?*

When it became necessary to make a distinction, it appeared desirable to consider vision to be the entire visual sense and seeing to be the entire human activity involved in the use of vision and in the performance of a visual task. This page of printed matter, considered abstractly, is a visual task. When one is reading this page it is a seeing task.

82. *Should we specify light for the most defective eyes or for normal vision?*

Certainly we should remember that many persons have subnormal vision. The level of illumination which results in a given see-level, or degree of visibility, for a given visual task for persons with average normal vision must be increased 5 or 10 times to provide the same see-level for persons with an appreciable degree of subnormal vision. Until the brightness of a visual task is considerably above 100 footlamberts, the ideal of easiest seeing is not reached even for persons with normal vision. This means hundreds—even thousands—of footcandles for some tasks involving low contrasts and low reflection-factors.

83. *What is meant by visibility?*

All things that are visible are not equally visible. This fact is not emphasized by the science of vision but is overwhelmingly important in the more inclusive science of seeing. The visibility of an object, or of a visual task such as this printed page, is a measure of how far it is above threshold visibility. It can be reduced to threshold by various means. A device so designed and calibrated to measure how much is necessary to reduce the visibility to the threshold of barely seeing reveals how much above threshold the object or task actually is. The measurement of visibility and the establishment of supra-threshold standards is one of the most important contributions of the science of seeing.

84. *Does the speed of light have any practical effect upon vision or seeing?*

Light travels about 186,000 miles per second. Speed of seeing commonly involves hundredths and even tenths of a second. Light travels 186 miles in one thousandth of a second. Obviously, for everyday seeing involving earthly distances the speed of light has no practical effect upon seeing.

85. *What is meant by the surroundings of a visual task?*

First we have the details of a task such as the letters and words on this page. Their immediate background is important. The entire page is a visual task. Its immediate surroundings are next in importance. Then we have the entire visual field diminishing somewhat in importance from this page to the outer boundary or periphery of the visual field. Arbitrarily we may assume the surroundings of a visual task to be the central part of the visual field confined to a solid angle of 60 degrees. In other words, the most important portion of the surroundings may be considered to extend 30 degrees in all directions from the line of sight or the center of the visual task.

86. *How does lighting affect production?*

Light and lighting are just as intimately and complexly associated with the quality and quantity of useful work done as vision and seeing are. Some effects are obvious but most of them are subtly accumulative over long periods for the benefit or to the detriment of everyone concerned. It is axiomatic that if light and vision are cooperating to make seeing efficient and easy, users of eyesight will be best served and they in turn will serve best.

87. *Why is it that accidents are not separated more specifically as to causes such as inadequate light, improper lighting, defective vision and poor seeing conditions?*

Some efforts have been made in these directions but the statistics are as yet relatively meager. Proper classification of accidents in terms of these causes can only be done by seeing specialists. Obviously there are few seeing specialists as yet and certainly they are not plentiful on police forces, among insurance adjusters, in the legal profession, and at other strategic points in relation to accidents. Aside from carelessness and mechanical failure most accidents involve seeing intimately and complexly.

88. *Is sodium light superior in tasks involving fine details?*

Sodium light is the only relatively efficient monochromatic light available at present. For many years it has been known that a monochromatic light is superior to a light of extended spectral range for seeing very small details near the threshold in size. However, this superiority practically disappears when the details are much larger than the smallest that are barely visible. Furthermore, the advantage of monochromatic light also decreases as the brightness-contrast between the details and their background decreases. It practically disappears for details of low brightness-contrast for the reason that their threshold size is many times greater than that of details of high contrast such as black objects on a white background. Obviously, under monochromatic light all colors become shades of a single hue.

89. *What is glare and why does it affect seeing?*

Glare is a rather indefinite term which must eventually be divided into various components. It is applied to light or brightness which decreases visibility and ease of seeing. Seeing is an activity of the entire human being and, therefore, glare is distracting in various ways. It not only decreases the sensitivity of the visual sense but also causes muscular, neural and mental strain. A bridge must carry its own weight and still be able to carry an additional useful load. The inevitable useless weight should be minimized and unnecessary useless load, after due esthetic considerations, should be eliminated. So it is with lighting and seeing conditions. Unpreventable glare should be minimized and preventable glare should be eliminated.

90. *How can one get enough light for sewing on dark goods and performing similar tasks?*

Such tasks require hundreds of footcandles to make the visibility of the critical details equal to that of newspaper body-text under ten footcandles. Such high levels of illumination can be obtained by adding powerful directed or localized light to the general illumination. To avoid having the surroundings too dark or too bright, they should have approximately the same reflection-factor as the task and the localized light should spread over an area of a few square feet. With such tasks it is important first to provide high levels of illumination and then do as much as possible to make other seeing conditions satisfactory.

91. *What is meant by seeing conditions?*

This is a rather inclusive term covering all factors which affect visibility and ease of seeing. Actually it includes the footcandles on the critical task itself. However, the term primarily emphasizes all the commonly neglected factors beyond the specific visual task itself. Conspicuous factors beyond the task are the brightness of the immediate surroundings and glaring light-sources, such as unshaded lamps and bright patches of sky in the visual field.

92. *What are the visual requirements for automobile drivers?*

Visual tests are generally so inadequate that only gross deficiencies stand in the way of obtaining a permit to drive. About 21 percent of all drivers wear eyeglasses. Of those past 60 years of age, about 65 percent wear eyeglasses. However, even with perfect vision, with or without glasses, the visibility-levels on highways at night are generally very low and the seeing conditions are commonly very poor. They can never be thoroughly safe from the viewpoint of seeing without a fixed artificial lighting system. Adequately safe seeing on the highway is generally more dependent upon light than upon eyeglasses.

93. *What is the normal reading distance for reading by children and by adults?*

The ideal reading distance would be to have the printed matter 20 feet away and, of course, having the type nearly 20 times larger than type to be read at a distance of 14 inches. There is no normal reading distance. As a matter of convenience we hold this book open in our hands or lay it on a desk within arm's reach. Normal eyes are more and more strained as the distance of the reading matter decreases from the ideal, but impractical, distance of 10 or 20 feet to lesser and lesser distances.

94. *Does safety depend upon speed of vision?*

Safety depends upon every aspect of visibility and of seeing and, therefore, emphasis upon speed of vision is not only an extremely narrow view but distracts attention from other factors which are more generally important. Even a casual examination of the extreme variety of accidents which are largely due to inadequate seeing conditions reveals that the time available for seeing is far more than adequate in most cases. Visibility is the primary factor involved, and high visibility of hazards is the best overall insurance against accidents due to poor seeing. Our attention must be forcibly aroused by adequate visibility—conspicuousness—of a stairway, a stair tread, a machine part, a warning sign, and countless other potential helps and hazards.

95. *How can I best see colors?*

After the proper choice of the illuminant, it can be readily demonstrated that a high level of illumination is most important. To distinguish with certainty small differences among socalled whites, 100 footcandles are more effective than a few footcandles. Colors of very low reflection-factors, such as socalled blacks, are best distinguished under levels of thousands of footcandles as are available outdoors in the daytime. The relatively low reflection-factors of many shades of colors, as exemplified by carpets and upholstering, require relatively high levels of illumination if one is to be certain of the color. These facts are easily demonstrated.

96. *Why not let the user of light choose what he needs?*

That practice was, and is, generally inevitable when the user knew, or knows, as much about the relationships of light, vision and seeing as anyone else. It was true of medical treatment when there was no science of medicine. Seeing, with its numerous details and consequences, is too complex to be adequately appraised by one who is not a specialist. A physician would be properly ridiculed if he opened his bag and permitted his patient to help himself. The seeing specialist can diagnose and prescribe light, and other aids to seeing, for those who have faith in him.

97. *Is the average person influenced in lighting and seeing by what he has been accustomed to?*

This is very generally true. In laboratory researches, subjects often express an opinion which they unknowingly prove to be erroneous. Criteria for measuring visibility and ease of seeing, which are beyond the conscious control of the individual, reveal the truth and also the unreliability of mere opinion. This is the universal source of progress in the science of seeing as in the science of medicine and all other sciences upon which practices are soundly established.

98. *Why is it difficult to read print on glossy paper?*

The two chief reasons are glare from the specularly reflected image of a bright source of light and also the decrease in brightness-contrast between print and paper. Place the printed matter on a flat desk and cover with a piece of glass. Also increase the level of illumination of the printed matter by means of another light-source to the left and rear. By observing closely one can demonstrate how glare can be reduced, how brightness-contrast can be increased, how the diffuse brightness is dependent upon the footcandles and various factors which influence seeing.

99. *What is the most important factor in seeing?*

After eyesight, corrected with eyeglasses if necessary, the most important factor is brightness. In fact, aside from color, we see nothing but brightness. Visibility depends upon the brightness-level and the brightness-contrast between the object and background. It also depends upon the brightness-distribution in the visual field. Learn to see, to appraise and to diagnose brightness conditions. Good brightness engineering is the way to high visibility and easy seeing.

100. *How can one demonstrate many of the facts of seeing?*

Many of the most important facts and subtly hidden effects of seeing can only be established by statistics obtained in researches under laboratory conditions. These cannot be demonstrated but many basic facts of everyday importance can be, as should be obvious from the foregoing chapters. Among the most striking demonstrations are special test-charts (Chapter XI), the visibility meter (Chapter XII) and various combinations of the four fundamental factors (Chapters VI to X). In all these the effectiveness of light as a partner of sight can be demonstrated in many ways, if one understands the basic facts and principles and recognizes them in the countless tasks of seeing.

References

The original papers and other sources referred to throughout the text have been minimized in number in keeping with the simplified and condensed presentation of the science of seeing. Most of them have been selected for the purpose of supplying fundamental knowledge upon which the discussions and conclusions are based. Many of them contain additional lists of references, particularly the books referred to. The latter also provide more detailed coordinations of the results of researches which have contributed toward the unraveling of some of the complexities of seeing. In making this selection, as in writing this book, the author has kept in mind the many requests for a presentation of widespread interest and practical value to those who would make seeing easier.

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Visibility and Ease of Seeing are closely related.

The visibility of an object increases as the level of illumination increases. Tasks of seeing become easier through the proper application of controlled lighting. Read the printed matter below. Read the two columns under different levels of illumination and note the line at which reading becomes difficult or impossible.

FOOTCANDLES FOR EQUAL VISIBILITY

15 The lines in these two columns
provide a series of visual tasks of
20 increasing difficulty from top to
bottom. The type-size in each
column remains constant, but the
brightness-contrast between the printed
30 matter and its background decreases
from a high value to a low value.
40 If an object is visible, it is by
reason of the facts that its size,
50 its contrast with its background, its
brightness, and the duration of its
image upon the retina exceed certain
75 limiting values. Obviously, the
threshold value of one factor is
determined by the magnitudes of the
100 other variables. Since complementary
relationships exist between the factors
of size, contrast, brightness and time,
a deficiency in one factor, within
certain limits, may be compensated
200 by an augmentation of one or more
of the other factors.
Each column affords an example
of an increasing deficiency in one
factor—brightness-contrast. To over-
500 come this deficiency, brightness may
be increased by increasing the level
of illumination. The visibility of all
the lines [illegible]
1000 [illegible]
2000
5000

Increasing size, within certain 10
limits, for any degree of
brightness-contrast between
the object and its background 15
increases the visibility. Com-
pare this column, printed with 20
larger type, with the first
column. The contrast across
both columns along any hori- 30
zontal line from top to bottom
is the same. The larger type 40
provides higher visibility 50
throughout. By increasing the
level of illumination, visibility is
further increased. If the levels 75
of illumination are supplied to
each of the lines as indicated, 100
visibility becomes equal for all
lines in both columns. Under
these conditions the relative 200
visibility of all lines becomes
four, [illegible]
[illegible] 500
1000
2000
5000

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